THE HOW AND WHY OF RADIO APPARATUS

A Treatise on the Principles
Underlying the Operation of Wireless
Transmitting and Receiving Instruments.

H.W. Secore, E.E.

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THE HOW AND WHY OF RADIO APPARATUS

A Treatise on the Principles Underlying the Operation of Wireless Transmitting and Receiving Instruments

With an Appendix on
"Calculation and Measurement of Inductance"

BY

HARRY WINFIELD SECOR

Associate Editor of the "Electrical Experimenter"
Associate Member Institute of Radio Engineers,
American Institute of Electrical Engineers

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WARNING

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AUTHOR'S PREFACE.

THE present volume covering the "How and Why of Radio Apparatus," comprises a series of papers, in which the function and use of the various radio apparata have been described in as simple a manner as possible, so that the average student of Radio-telegraphy and telephony, can obtain the utmost practical value from them. The author has found in his experience with radio students, that it is a common failing for them to be posted on a more or less extensive range of electrical and radio principles and laws, but they frequently do not understand as they should, the basic principles on which the various instruments work. For example: It is not sufficient to know how to connect up a loose coupler or tuning coil, or detector, so that the circuit will receive radio signals, for an occasion may arise, where it is desirable and in fact imperative, if success is to be obtained, that one should know just how the apparatus works. Springing from such fundamental facts, the ambitious and intelligent student of radio matters, can proceed to design and construct apparatus either for himself or in emergency when he may be shipwrecked, or also in time of war, etc.

The aim of the author has been throughout to minimize the use of mathematics, although every radio student knows that the thorough study of radio-telegraphy and telephony involves considerable mathematics. But, as will be seen, the present articles have been kept as free as possible from any involved formulas, which are a stumbling block to many ambitious students and radio experimenters. The present treatise is not a pretentious volume, intended to cover all types of radio apparatus, for it is not conceivably possible to do justice to every type of apparatus in a single work such as this—in fact, radio apparatus is being changed so rapidly, that it would only be a waste of time, generally speaking, to attempt such an exhaustive treatise on the subject. The commercial and experimental radio supply companies usually prepare complete bulletins, giving data and circuits for their newest apparatus and instruments, so that what the student really wants in the form of a text-book, such as this, is a course of instruction on the general and usual types of such apparatus, and this has been the aim throughout.

The three final chapters of this work cover the calculation and measurement of inductance—a subject which every radio student sooner or later comes in contact with, and one which as the old adage

has it—"will master him if he does not master it." The formulas and graphic curves given in this part of the work have been simplified to such an extent, that it is thought that the average student will have but little difficulty in understanding and applying them to his immediate requirements. It was all very well a decade ago, to multiply the length of the wire on the tuning coil by four, and take the answer for the wave length of the coil. But today, the radio art has progressed, until practically every student, even the youngest, knows that an aerial actually has capacity and inductance as well as resistance. Also he knows that the lead-in has a certain capacity and inductance, and that if he wishes to know the wave length at which a certain loose coupler or loading inductance will oscillate, that he must accurately determine by measurement, or else calculate by accurate formulae such as here given, the exact inductance of the coil, as well as the capacity and inductance of the lead-in; the ground wire, and also the flat top. This part of the work may seem abstruse and unnecessary to many young radio men, but the author wishes to drive home the point, that the student will live to bless the day when he first mastered the underlying mathematical principles and their relations to the calculation of wave length and frequency, in both the aerial and detector oscillatory circuits.

In closing, the author would like to say that if the student wishes to become a thorough master of any specific subject, such as Radiotelegraphy and telephony, that he not only should, but must, read all the different books on the subject which he can procure. If he cannot purchase them, then he can invariably procure them from the local library, or his friend's library. No one book covers everything, and if it did, you would not want it. There are too many changes and advances along certain specific lines, as for instance, in the Audion or vacuum tube field. If you want to know all about Audions, then by all means procure a book on that subject, of which there are several available. If you wish to go into the design of transformers, then you will save a great deal of time and misdirected effort by looking up specific books treating on this particular subject.

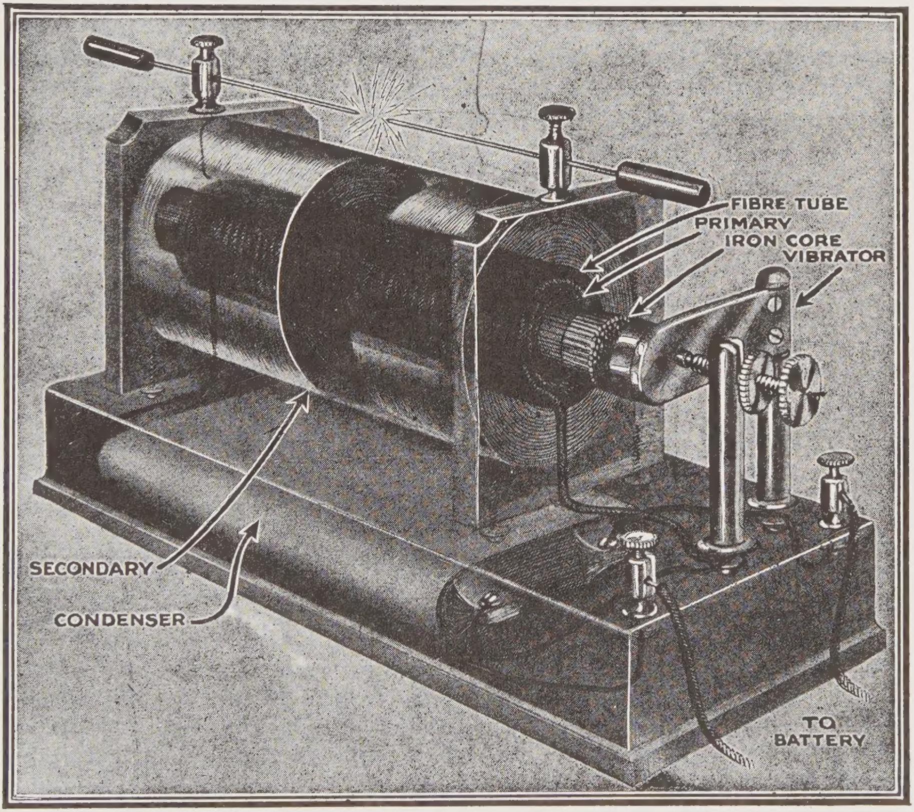
The author desires to express his thanks for the cooperation of Mr. Samuel D. Cohen in the preparation of the final chapters, covering the "Calculation and Measurement of Inductance," and also wishes to express his appreciation to Prof. F. E. Austin, Professor of Electrical Engineering at Dartmouth College, Hanover, N. H., who has very kindly read the manuscript of this book.

H. WINFIELD SECOR.

CHAPTER I.

The Induction Coil.

THE induction coil is in general made up of two distinct windings or coils which are usually arranged one over the other, having an annealed iron wire core passing through their center, as shown in Fig. 1.



The diagram at Fig. 1 shows in a schematic manner the arrangement of an induction coil designed to produce sparks or high voltages. Usually, at least in wireless work, the primary, or heavy wire winding is placed over the iron wire core. Suitable insulation, consisting of a few layers of insulating cloth or paper, is placed over the iron core

preparatory to winding on this coil. After the primary has been completed, which generally consists of two to three layers of comparatively heavy wire, it is carefully insulated by winding over it several layers of insulating cloth; in spark coils above one quarter inch rating it is preferable to place a hard rubber tube over it.

The secondary winding is wound on over this tube, and this coil is usually somewhat shorter in length than the primary.

Now, when the primary switch of such a coil is closed, the battery current passes through the primary winding on the core and magnetizes the core. This attracts the iron armature on the vibrator spring, as shown in Fig. 1, and when this spring breaks contact with the platinum tipped screw in front of it, the primary circuit is opened.

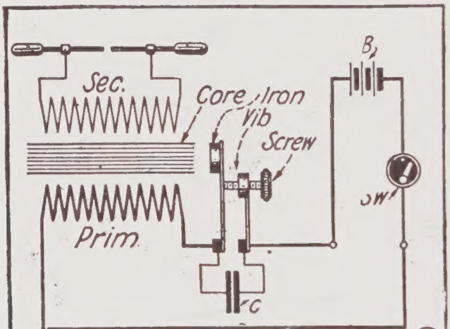


Fig. 1

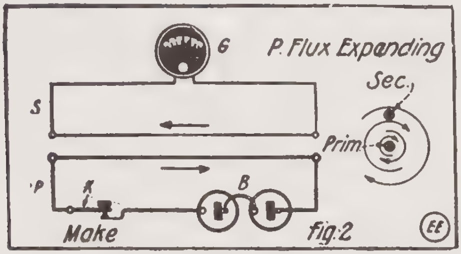
At this juncture there is induced in the secondary winding a very high pressure. The spring-actuated vibrator returns to its former position in the fraction of a second and the process is repeated all over again.

Small induction coils used for medicinal purposes, such as the treatment of rheumatism, etc., are practically never fitted with a condenser across the vibrator. All spark coils, however, are invariably equipped with such a condenser, which reduces the spark at the vibrator contacts and also greatly enhances the intensity of the induced secondary current.

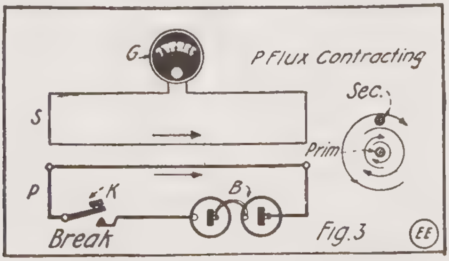
It is generally considered, and is stated in most text-books on this subject, that the voltage of the current induced in the secondary winding will be proportional to the ratio existing between the number of turns of wire in the secondary winding and the number of turns in the primary. This ratio holds true for regular alternating current

transformers, but it does not hold exactly true for ordinary induction coils, as the potential of the secondary induced current is, to a great extent, proportional to the speed of the vibrator interruptions.

We may examine the phenomena taking place at both the *make* and *break* of the spark coil vibrator, by referring to Figs. 2 and 3.



As will be evident from Fig. 2, the *primary* current, during the direction of the induced current in the secondary is opposite to the direction of the primary current, during the *make* period at the vibrator. This is in accordance with the law of Lenz, which states *that the direction of a current produced by electro-magnetic induction, is always such as to cause it to oppose the motion by which such currents were pro-*



duced. The half wave of secondary current induced at *make* is not of very high value, and is termed the *inverse current.* The phenomenon taking place at the *break* of the primary circuit vibrator or interrupter is exhibited at Fig. 3. Here the secondary current passes in the same direction as the primary current. It is, moreover, of very high instantaneous value and possesses much greater energy than the inverse half wave B, shown graphically in Fig. 4.

This may seem at first quite contradictory to the statement of Lenz's law, but upon reflection it will be evident that when the primary circuit is open, the primary current magnetic flux lines are caused to cut the secondary turns in a direction opposite to that at *make* of the circuit. Figs. 2 and 3 will make this quite clear, as the expanding and contracting lines of force are clearly shown therein.

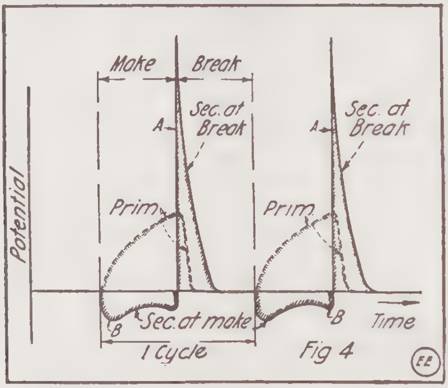


Fig 4

From this discussion, as well as from the illustration given in Fig. 4, it becomes evident that in the ordinary induction coil, in the medical coil for instance, a pulsating direct current passing through the primary winding is transformed into an unsymmetrical, alternating current in the secondary winding; the half waves of which are not alike. In the spark coil, however, where the secondary potential is sufficient to create a disruptive spark, the direct current passing in the primary is transformed into an unsymmetrical, alternating current in the secondary only, when the spark gap is sufficiently short to allow the weaker, or inverse half wave B, of the current to jump it. If the gap is too long for the B half wave to leap across it, then the secondary current is practically a unidirectional one.

It is possible to test the polarity of the secondary terminals by means of pole test paper, or a standard liquid polarity indicator may be utilized. If two pieces of fine iron wire are connected to the secondary terminals of the spark coil, one of them will become very hot and the other will remain cold; the cold one being the positive terminal of the coil.

As shown by the oscillogram Fig. 4, which is that for a small spark coil fitted with a vibrator shunt condenser, the duration of the primary current at the *break* of the interrupter is quite short. The duration of this portion of the primary current is kept as short as possible, and aided in so doing, to a large extent, by the condenser shunted across the vibrator. This condenser absorbs the extra or self-induced current of the primary, which would otherwise unduly prolong the demagnetization of the iron core. The general wave form of the primary current, and sensibly also its potential, is similar to that shown at Fig. 4. When the interrupter closes the primary circuit, the primary current rises slowly to a maximum and at the rupture at the interrupter, the primary current and potential fall quite rapidly to zero. The quicker the break of the interrupter and the faster the demagnetization of the iron core, the more pronounced the intensity or potential of the secondary induced wave, A. This is shown graphically, and in a striking manner, by the oscillogram.

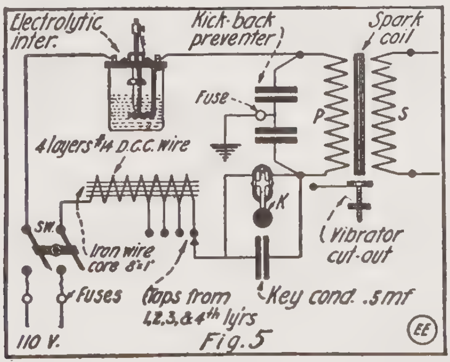


Fig. 5

Small spark coils may be operated in the regular way from A.C. step-down transformers. Where 110 volts A.C. or D.C. is available, it is a good idea to operate the spark coil with an electrolytic interrupter; see Fig. 5. Small coils, such as the ½ or 1 inch variety, should not be hooked up directly to 110 volt circuits, but should have a suitable choke coil in series with the primary winding and the electrolytic interrupter. All such installations should, no matter how small, be equipped with a kick-back preventer of approved form. It is required in all cases by the Fire Underwriter's rules governing radio installations operating on commercial light and power circuits.

CHAPTER II.

THE TRANSFORMER.

THE first chapter dealt with the action taking place in the induction or spark coil as used for wireless and other purposes. In the present discussion we will consider the action occurring in that class of apparatus known as the alternating current *transformer.*

There are two distinct types of transformers, viz., the *open* and *closed core* type. The open or straight core transformer is shown schematically at Fig. 1 and the core consists of a laminated iron structure made of core wire or iron sheets, properly bound together with tape or placed in an insulating tube. Over this tube is wound the *primary* coil, consisting of two or more layers of relatively heavy insulated copper conductor. The *secondary* coil, wound in a number of small sections or in some cases on large spools, is then slipped over

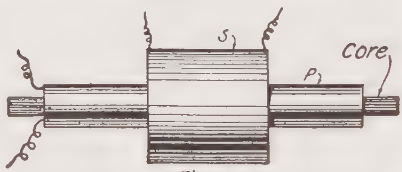


Fig. 1

the primary, care being taken to thoroughly insulate the two windings by placing the primary and core within a heavy walled insulating tube of hard rubber, or some other equally efficient insulator.

The closed core transformer, Fig. 2, has its magnetic circuit entirely closed and is therefore, as might well be imagined, the more efficient of the two. This is so for the reason that the magnetic flux produced by the primary coil P can complete its circuit entirely through the laminated iron core which links the *secondary* winding *electro-magnetically* with the *primary.* In the open core transformer, one end of the core is of a different magnetic polarity from the other and the magnetic flux has to thread its way from the *North* pole to the *South* pole, through the air as shown in Fig. 3, and thus encounters an extremely high *reluctance,* as the term for magnetic resistance is known, thereby lowering the electrical efficiency considerably in this type of transformer.

Referring to Fig. 1A, which illustrates an hydraulic analogy of the alternating current transformer, it is seen how a small quantity of water at high pressure may perform work or transform its mechanical energy through the medium of a double cylinder pump, resulting in the water issuing from the large cylinder being expelled in a large quantity at low pressure. For example, suppose that the high pressure water stream enters the small cylinder at the right at a pressure of 100 pounds and with a quantity of 10 gallons. If this energy is utilized in pushing forward a piston connected to a steel rod and a large piston, in the cylinder at the left, fitted with a large efflux pipe,

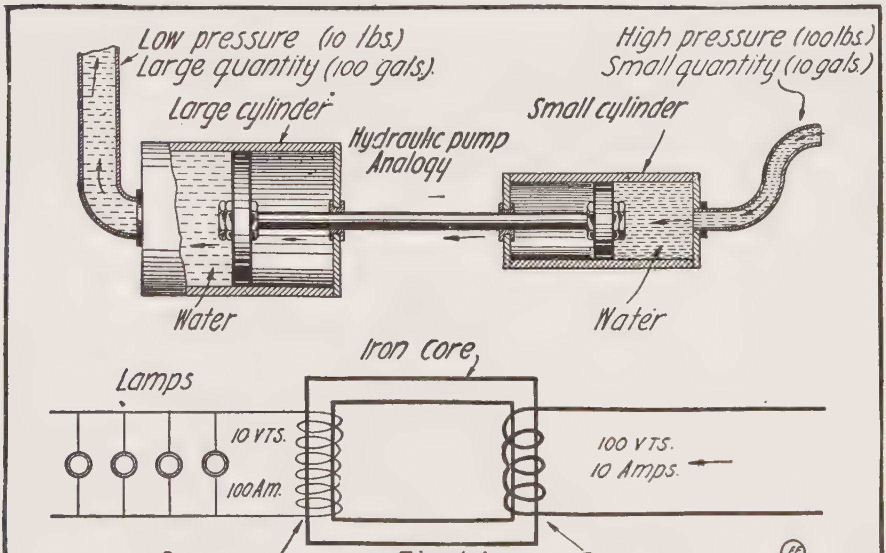


Fig-1-A

then the water in this cylinder will pass out in a large quantity, say 100 gallons, at a low pressure, say 10 pounds. It is the same with the A.C. transformer. The primary winding corresponds to the small, high pressure water cylinder and may be supplied, for example, with a current of 10 amperes at a pressure of 100 volts. Considering that this transformer is of the step-down type, then the secondary (corresponding to the hydraulic analogy), may have a current of 100 amperes passing through it at a pressure of 10 volts.

Generally speaking, the voltage ratio between the primary and secondary windings is directly dependent upon the ratio existing between the number of turns in the primary coil and those in the secondary coil, i.e., if there are 2,000 turns in the secondary and but 100 in the primary, then if the applied primary potential is 100 volts, the *induced* secondary potential will be twenty times this value, or 2,000 volts, for the reason that 2,000 divided by 100 gives twenty as the *transformation ratio factor* for the two windings. Conjointly, the secondary current in amperes will be reduced accordingly and inversely it will be, theoretically speaking, one-twentieth of the primary current in amperes. Thus we see that no transformer can produce more energy in its secondary circuit than that passing through the primary circuit. Moreover, no transformer ever built will produce the current and voltage values in the secondary as just stated, as there is always some loss due to the transformation actions occurring within the transformer, which loss depends upon the size of the transformer and also whether it is of the closed or open core type.

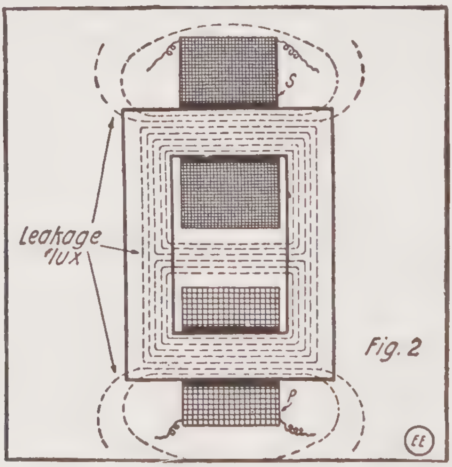
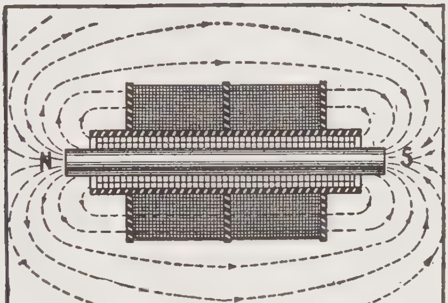


Fig. 2

The usual efficiency of transformation for open core transformers is roughly 60%, but this of course will vary with the size and construction of the transformer. Closed core transformers realize as high as 85 and 90% overall efficiency, even in small sizes as low as 1 K.W. rating, and in large size commercial transformers used for lighting and power work, the net efficiency often reaches as high as

98% and more. This efficiency expresses the relation between the net watts *primary input* and the net watts *secondary output*, or the efficiency is the ratio of the useful output to the total input.

Thus, if a transformer is rated at 1 K.W. or 1,000 watts, it is usually understood that this is the secondary output, and if its gross efficiency was 94%, then the primary input would have to be 1063.83 watts and the difference between the two, 63.83 watts, would be that consumed by the iron and copper losses in the transformer.



Leakage flux
Fig. 3

Transformers operate in a manner analogous to the well-known induction or spark coil described in the first chapter. The action in general is based on the fact that when an alternating current of any certain frequency is applied to the primary or exciting winding of the transformer, this will cause the iron core to become magnetized and demagnetized many times per second. This cycle of magnetization, first in one direction, then to zero and remagnetization in the opposite direction, occurs once for every cycle of the alternating current applied to the transformer; that is, if the primary current has a frequency of 60 cycles, then the magnetic flux set up will pass around the core first in one direction, and then in the opposite direction, at the rate of 120 times per second. As will become manifest, this will give rise to powerful induced pressures in the adjoining secondary winding, which will have characteristics of a similar nature; that is, they will be pressures similar in nature to those in the primary or alternating pressures of like periodicity or frequency.

A great many people have the idea that a transformer of the step-up or step-down type will change the frequency of an alternating current. But while this is so for certain peculiar arrangements of transformers and auxiliary cöacting devices, this is not primarily so in the ordinary transformer generally found in experimental wireless and electrical laboratories.

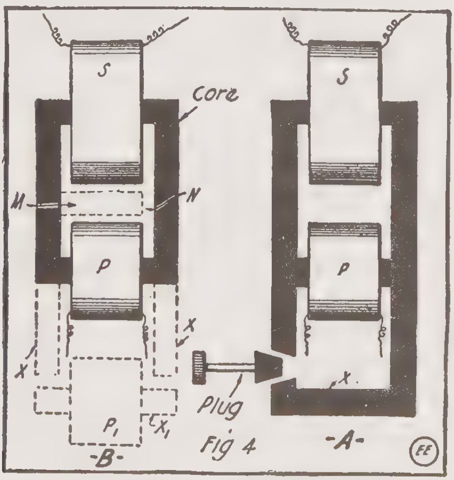
The transformer, in the ordinary case, simply raises or lowers the applied primary potential or voltage with a consequent change in the current in amperes as previously explained.

Transformers always draw a small current, even with the secondary open, which is required for magnetization of the iron core. A transformer is said to be operating on zero load when the secondary circuit is open. With this condition of no current in the secondary winding, there is a very small current in the primary winding for the following reason: The current in the primary winding will cause an alternating magnetic field to be set up through both the primary and the secondary windings, which induces an electromotive force in both of them. This induced E.M.F. is in the opposite direction, to the E.M.F. impressed upon the primary winding and very nearly equal to it. It is only this difference in E.M.F. that is available for producing a current in the primary winding, and since this difference is small, there will be a small current in the primary winding when there is no load on the transformer. This current is called the *no-load current* of the transformer. The induced E.M.F. in the secondary coil is in phase with the E.M.F. induced in the primary, and it is in opposition to the impressed E.M.F. on the primary, or the primary and the secondary E.M.F.'s are displaced in phase by 180°.

Now if the secondary coil of a transformer be connected to a receiving circuit and delivering a current, the transformer is said to be *loaded.* Since the E.M.F. induced in the secondary coil is 180° from that imprest on the primary coil, the current in the secondary coil will produce a magnetizing effect which tends to lessen that produced by the small current already in the primary coil. Hence the variations in the magnetic flux passing through both of the coils is decreased, which results in a decrease in the induced E.M.F. in the two coils. This decrease in counter E.M.F. in the primary coil results in an increase in the difference between the imprest E.M.F. and the counter E.M.F. which results in an increase of current in the

primary coil. If the load on the secondary coil be increased or decreased there will be a proportional increase or decrease of current in the primary coil.

There have been a number of odd transformer designs brought out in the past few years and intended especially for radio work; one of the best of these is shown schematically at Fig. 4-A. This represents the well-known Thordarson transformer, in which the primary, and consequently the secondary, current is controlled or varied by effecting a change in the *reluctance* of the magnetic circuit of the primary coil. It is possible with this transformer to shunt more or less of the primary flux through an auxiliary laminated iron branch core X. This branch core may have its magnetic reluctance varied



by means of a tapered iron plug as shown, which works on a gear attachment so that it may be inserted more or less into the wedge-shaped gap in the main core. The further this plug is inserted into the gap, the more pronounced the primary self-inductance and the smaller the current consumed, and of course the current in the secondary is also reduced correspondingly. As this iron plug is removed from the gap the primary and the secondary energy increases.

Several years ago there was a very unique and efficient radio transformer brought out and which is shown by the diagram at Fig. 4-B. This closed core transformer was constructed with two project-

ing laminated iron core legs, X—X, which could be shunted by a movable iron core leg X_1, carrying the auxiliary primary coil, P_1. It will be readily seen that this design provided excellent opportunities for a fine regulation of not only the input and output of the transformer, but also of the general resonance or tuning characteristics.

An adjustable choke coil of suitable proportions connected in the primary circuit of a radio transformer will aid considerably in tuning a complete transformer radio set, as has been found by the Marconi Company; and practically all of their radio sets are equipped with suitable choke coils for this purpose.

One of the leading manufacturers of experimental radio transformers has favored a closed core design with an auxiliary laminated leg as shown at M, in Fig. 4-B. This auxiliary leg is shorter than the coil legs so as to leave a small air gap N. Of course, with this scheme, the transformer, once it is built, is set, so far as its regulation and leakage is concerned, and does not possess the tuning and regulating characteristics that such a transformer as that shown in Fig 4-A would manifest.

A discussion of the importance of resonance tuning characteristics in radio transformer circuits is given in the work *Wireless Telegraphy* by A. B. Rolfe-Martin. If we insert a variable inductance in the primary circuit of a transformer, we have a ready means of tuning the whole arrangement to any desired period within limits. Furthermore, a suitable inductance in the primary circuit will control the input in the transformer and hence the output as aforementioned, and will prevent arcing across the spark gap in the secondary circuit almost as effectively, if not quite as well, as when choke coils are connected between the secondary terminals and the leads of the oscillatory radio-frequency circuit.

It is well to mention here that all of the best transformer type radio transmitting sets, however, are equipped with light *air-core* choke coils connected to the secondary terminals, which serve to protect the transformer secondary winding from any reflex oscillations or static kick-backs from the condenser-helix-spark gap circuit which, in many instances, has resulted in the rupturing of the insulation in the transformer, necessitating its entire rewinding. The primary choke coil, moreover, need not be insulated to withstand the high tension of 15,000 to 20,000 volts produced by the secondary.

There now remains the question of the period that the low or primary frequency circuits are to assume, and they should preferably have the same period as the alternating current supply. If, for instance, we assume that the secondary oscillation condenser has .04 mfd. (4×10^{-8} farad) capacity and a transformation ratio of 20,000: 100 or 200, then, if we desire to design a suitable primary inductance, such that it will give a natural period to the entire low frequency arrangement equal to the period of an alternating current supply having a frequency of 200 cycles, then the time period in seconds would be equal to 1/200th second.

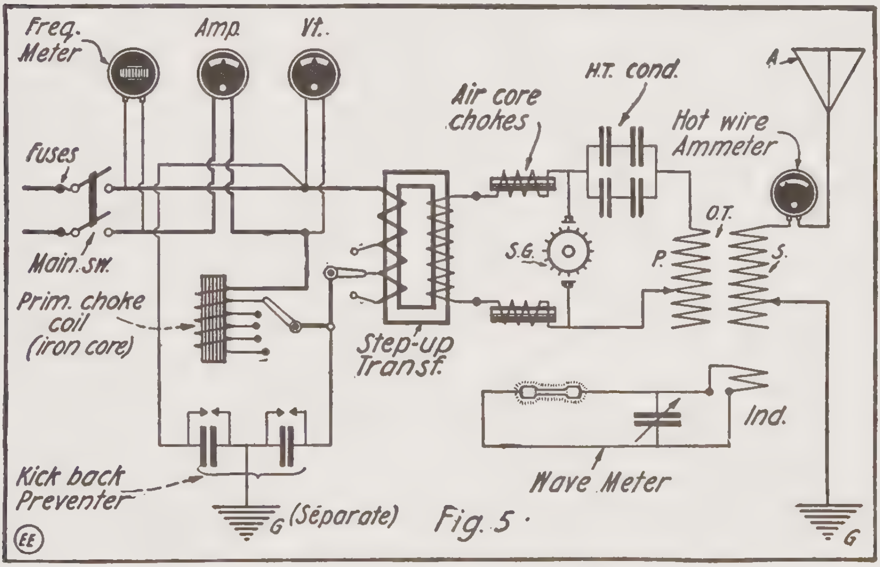


Fig. 5.

As the time period then of such a system is equal to 1/200th second and substituting the known terms in the time period equation:

$$t = 2\pi T \sqrt{LC}$$

in which T is transformation ratio, we get:—

$$1/200 = 2\pi\, 200 \sqrt{4 \times 10^{-8} \times L}$$

or

$$\sqrt{L} = \frac{1}{16\pi}$$

which gives us a value for L of approximately .0004 henry. This is well within the design limits of a convenient primary choke or impedance coil.

In the design of complete, isolated radio transmitting sets there is one other inductance in the primary transformer circuit—that of the alternator armature; and this somewhat modifies the calculation for exact results. A wiring diagram with adjustable primary choke coil and also secondary terminal, air-core chokes is given at Fig. 5, which includes the kick-back preventer, composed of two ½ M.F. condensers shunted by spark gaps and grounded as shown.

CHAPTER III.

RADIO TRANSMITTING CONDENSERS.

THE electrical condenser may be likened to a hydraulic mechanism corresponding to that illustrated at Fig. 1, wherein we have two similar compartments, A and B, joined together by means of a valve, whch may be turned so as to cut off one compartment from the other. If we fill the compartment A, with water, then we might consider the A side of the device as representing *positive* potential or polarity of one kind, and the B side of the device as representing *negative* potential or polarity of an opposite kind; the same as is the case with electrical condensers.

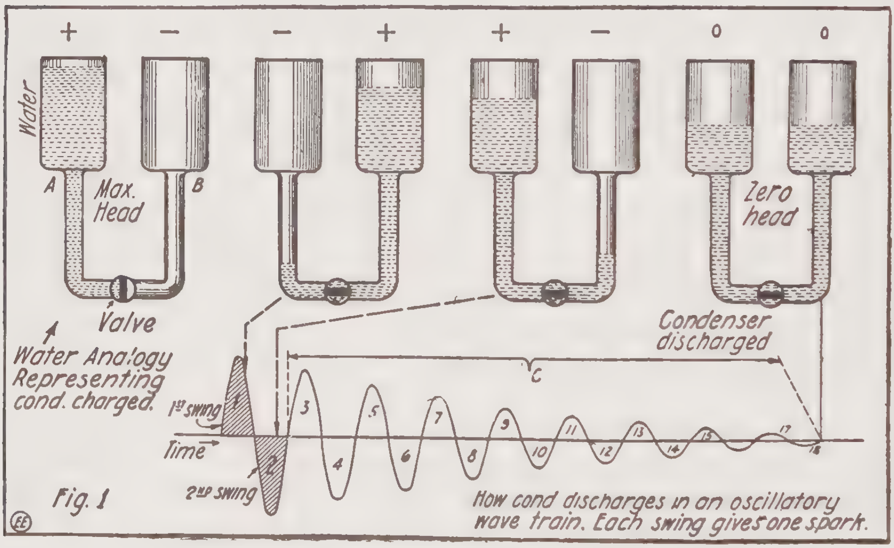
If the valve is now turned so as to allow the water in chamber A, to pass into the chamber B, then we may consider that the potentials have changed places, i.e., the B chamber now represents *positive* potential, while the A compartment represents *negative* potential. If the valve is properly regulated as to the size of opening, the water will return from chamber B, into chamber A at the left. This action will repeat itself a number of times, the water rising and falling alternately until, eventually, they come to rest, as shown in Fig. 1, at the extreme right, which we may take to represent *zero head* or the point of *full discharge* for the electrical condenser. And it will be noted also that there is no further movement of water through the valve when this stage is reached.

The successive oscillations or swings of the water column as it rises first in one compartment, and then in the other, is indicated by the oscillatory curve at the bottom of Fig. 1. An electrical condenser behaves in a similar manner when it is discharged through a suitable circuit and the potential and current oscillates or swings back and forth through numerous positive and negative waves as seen. Only oscillations 1 and 2 are shown hydrostatically, but the water, similar to the electrical condenser, will continue to swing up and down, so to speak, until the wave train is complete, as indicated by the extended section C.

If the valve in the hydrostatic apparatus is made to have a sufficiently small opening, then the oscillations will not occur, but the liquid will rise slowly in the opposite compartment in a single surge. This corresponds with the action of the electrical condenser, in which case, if the discharge occurs through a long thin wire then no os-

cillations will take place, but the condenser discharge current will take a longer time in which to die away to zero (in a single surge); if discharged through a relatively shorter and thicker conductor, then the condenser will discharge more quickly and in an oscillatory manner. Whether or not a condenser discharge will be oscillatory or non-oscillatory may be determined by inspection of Thompson's equations:

Where:—L is inductance of circuit; C its capacity and R the resistance.



$$R^2 < \frac{4L}{C}$$

oscillatory discharge

$$\text{Or } R^2 > \frac{4L}{C}$$

non-oscillatory discharge

A few interesting points with respect to the physical action of electrical condensers will be mentioned briefly. A great many believe that, given a condenser composed of a glass plate coated on both sides with metal leaves, and when this is charged by connection to a static

machine or other source of high tension current, the metal leaves of the condenser hold the charge. That such is not the case is readily proven by simply removing the two metal leaves from proximity to the glass plate and discharging these metal elements by connecting them to a grounded conductor. If, now, the metal plates are again placed in contact with the glass plate or dielectric and the condenser terminals are joined to a galvanoscope or electrometer, it will be found that a powerful discharge takes place, indicating that the electrical discharge resided, not on the metal plate, *but in the dielectric.*

Early investigators, among whom Faraday was a prominent one, assumed that when a condenser is charged, the whole phenomenon is not fully described by merely stating that one plate gathers *positive* and the other *negative* electricity. This assumption of lack of definiteness was taken up by Maxwell, he making the assumption that, although the plates of the condenser be separated and kept apart by an insulator, an action takes place in the insulator itself which is something like the action of electricity flowing through a conductor.

Exactly what means Maxwell employed to work out his idea along this line is unknown, but Professor Pierce represents Maxwell's idea by supposing that the insulating medium of a condenser, whether it be glass, oil, or air, is made up of small parts and that the electricity in these small parts of the dielectric or insulator may flow easily in the small parts themselves, but cannot flow from one part to the next. This may be on account of the insulating properties of the dielectric. If we think of these small parts as molecules, this assumed current in the dielectric may be the action of polarizing the molecules. For illustration, assume that the two plates of a condenser in Fig. 2 marked + and – which are separated by a dielectric, are being charged by the battery B. The + plate at the left is attracting negative electricity and repelling positive electricity in the layers of molecules nearest it, and that part of each molecule of the layer nearest the positive plate by the law of charges, becomes negative, and the part farthest from the positive plate, becomes positive. Molecules in this condition are termed *Polarized Molecules.* Each layer of the molecules thus polarized will act upon the next layer, producing the same effect of polarization, so that all the molecules of the entire dielectric acquire this polarization.

Some investigators have stated that this action is typically and

merely electricity produced in induction, and although there is not an actual transfer of electricity between the dielectric molecules themselves, as we would think of electricity being transferred on a conductor, the effect of this general transfer of electricity by Induction is the same as if the dielectrics were a conducting substance. This transfer of electricity in the dielectric, Maxwell called a *Displacement Current.*

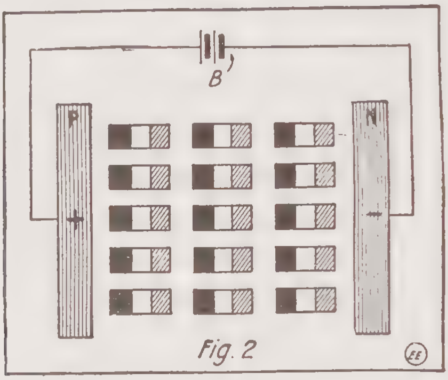


Fig. 2

When a condenser is being charged, the directions of the charging current and the displacement current are the same, so that the electrical circuit may be said to be completed through the condenser by the displacement current. At discharge, Pierce states that the dielectric loses its polarity and gives rise to a displacement current in it. Like the action of discharging, the action of the displacement current completes the circuit for the discharging current.

High tension condensers for radio transmitting requirements are very often, especially for experimental sets, built up from a number of glass plates coated on both sides with oppositely charged metal leaves.

Referring to Fig. 3, it is at once apparent how the alternate metal leaves are connected to the opposite terminals T_1 and T_2. In constructing high voltage condensers in this way, it is always best to round off all the corners of the metal plates, so as to reduce the brush discharge to a minimum; and coating the glass plates with asphaltum paint will also reduce the brush or corona leakage, which becomes a considerable factor when the condensers are operated at very high potentials. If serious trouble is encountered in this direction, it

behooves us to increase the insulation as much as possible, and this can be well taken care of by immersing the complete assembly of glass and metal plates in a glass or other jar containing a good insulating oil such as boiled out linseed oil or Transil oil. Paraffin oil is also used for this purpose. In calculating the capacity of condensers, it should be noted that it is only the *active dielectric surface* that counts, i.e., the area of dielectric (glass, etc.) covered *on both sides* with metal charging plates equals the effective length "l" times effective width "r." The thickness of the dielectric is represented at "d."

Some constructors prefer to mount the glass plates about one-half inch or so apart in a suitably grooved wooden frame, each glass plate having a tin or other foil leaf cemented fast to the glass by means of thin shellac or, better still, banana oil. The metal leaves are readily rolled down tight on the glass so as to squeeze out all air bubbles by means of a rubber print roller such as is used by photographers. Condensers most always break down at the point where air bubbles

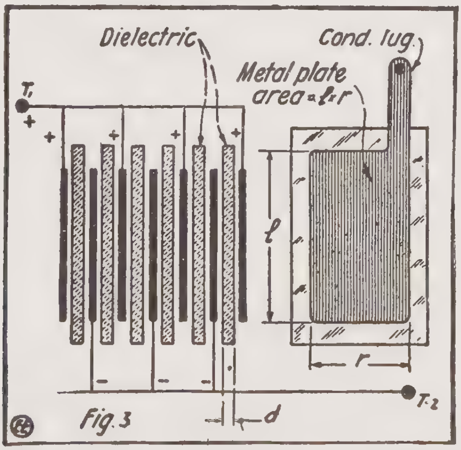


Fig. 3

are present, hence, every precaution should be taken to eliminate them. Some have even gone so far as to sand blast the glass plate surface, and then, by suitably treating the roughened surface, to coat it firmly with a copper plate deposited electrolytically on it. The glass plates are usually coated first with a dressing of plumbago (grafite). Another method is to burn the copper or other metal directly into

the glass surface by placing the glass dielectric in a suitable oven, in which the temperature can be raised to approximately or nearly the fusing point of glass.

A set of direct-reading condenser capacity curves are given at Fig. 4, whereby it is possible to ascertain the required capacity of a condenser for all average sizes of experimental, radio transmitting transformers, and the formula by which these curves are calculated and plotted is given below so that the reader may compute the proper

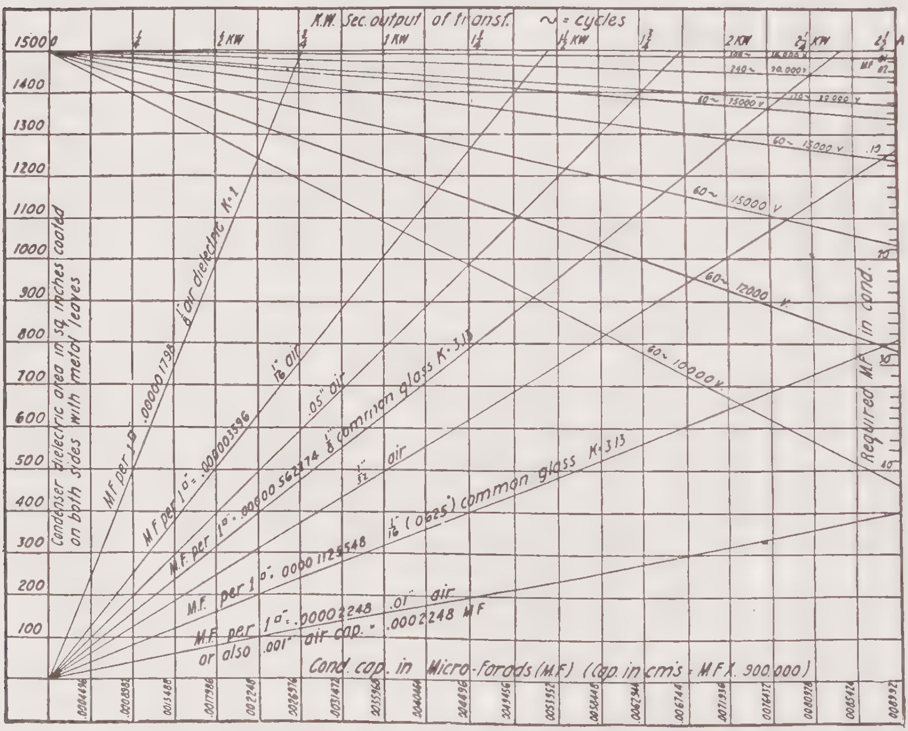


Fig. 4. Direct reading curves for transformer capacity.

capacity for any special problem not covered by these curves. For instance, it is found that for a sixty cycle 1 K.W. step-up transformer, delivering ten thousand volts at the secondary, there will be required a high-tension, secondary condenser for the closed oscillating circuit, having a capacity of .165 microfarad. Knowing the required capacity of the condenser it is next necessary to select the proper number of

glass plates and their size as well as their thickness. Generally speaking, it may be said that for amateur requirements it is usual to employ about 1/16-inch glass plates for potentials under 10,000 and ⅛-inch glass plates for potentials up to 18,000. This matter may be gone into more precisely by referring to any electrical engineering handbook such as "The Standard Handbook for Electrical Engineers," wherein the dielectric strength in volts per mil is given for various insulators.

The curves given at the bottom of Fig. 4, enable one to compute the required *active area* of dielectric for the above or other capacities and the results will be found very close if the mf. (micro-farad) per one square inch, as given on the various curves, is divided into the total mf. capacity required.

The ordinates at the left are for various *active dielectric areas* in square inches, coated on both sides with oppositely charged plates, and by reading from these values across to the dielectric curve and then from this point downward, the corresponding capacity in mf. will be found.

A resumé of the principal formulæ involved in the calculation of condensers is given below.

The *farad* is the basic unit of capacity. It is that capacity resultant from 1 coulomb raising the potential of a condenser from zero to 1 volt. The farad is a relatively large unit and the *microfarad,* (the one-millionth part of a farad), abbreviated m.f., or u.f., is used for all ordinary purposes. The several sub-divisions of the unit of capacity in common use are as follows:

Microfarad $=10^{-6}$ farad (m.f.).
Milli-microfarad $=10^{-9}$ farad.
(Also called Billifarad.)
Micro-microfarad $=10^{-12}$ farad.
(Also called Picofarad.)
1 farad is equivalent to 9×10^{11} centimeters in electrostatic units.
1 microfarad $=9\times10^{5}$ centimeters in E.S. units.

The formula for calculating the capacity of condenser is:

$$C=\frac{885\,K\,a}{d\times10^{10}}\ (\textit{for cm. measurements})$$

$$C=\frac{2{,}248\,K\,a}{d\times10^{10}}\ (\textit{for inch measurements})$$

Where: C=Capacity in microfarads.

K=Inductivity factor of dielectric. (See table below.)

a=Area of all the dielectric sheets *actually* between and separating the metal condenser plates.

Also a=number of insulating sheets covered on both sides by oppositely charged plates multiplied by area of each sheet.

d=thickness of dielectric sheet.*

Condensers in parallel:

$$\text{Joint capacity} = C_1 + C_2 + C_3 + \text{ etc.}$$

Condensers in series:

$$\textit{Joint capacity} = \cfrac{1}{\cfrac{1}{C_1} + \cfrac{1}{C_2} + \cfrac{1}{C_3} + \textit{ etc.}}$$

Series—Parallel condenser circuits:—Compute joint capacity of each branch (with condensers in series) and then compute joint capacity finally for the number of branches in parallel.

Computing energy in condensers:—

E=Volts across condenser terminals

C=Farads capacity of condenser

Q=Coulombs in condenser

Then:—Q=C×E;

$$C = \frac{Q}{E}; \; E = \frac{Q}{C}.$$

Capacity of rotary variable condenser in microfarads.

$$C = \frac{2{,}248 \times (3.1416\, R^2 .5n) \times K}{d \times 10^{10}};$$

Where: R=Radius of movable plates in inches

n=Total number of air spaces actually between moving and stationary plates.

d=Thickness of air space between a moving and fixed plate in inches.

K=Being 1 for air, is here ignored except when oil bath is used.

Effective current in amperes taken by condenser on A.C. circuit:

$$I = \frac{E\, C\, 2\, \pi f}{1{,}000{,}000};$$

E=Effective A.C. volts.

C=Capacity condenser in microfarads

* The measurements are taken in square centimeters and square inches, respectively, for the different formulae. The thickness must be taken in centimeters also, if the area is taken in square centimeters, and vice versa.

f=Frequency in cycles per second of charging current
π=3.1416

Capacity of condenser required for different sizes of wireless transformers:—

$$C.\,mf. = \frac{K.\,W. \times 10^9}{V^2 \times f}; \text{ (based on 2 sparks per cycle)}$$

Where K.W.=Secondary output of radio transformers in kilowatts. Transformers are generally rated in secondary output.

V^2=Sec. volts (effective) squared.

f=frequency in cycles per second of transformer primary current and based on 2 sparks per cycle or 1 per alternation.

10^9=1,000,000,000

For sets using a rotary spark gap:—

$$C.\,mf. = \frac{2 \times W \times 10^6}{N \times V^2};$$

Where:—W=Power in watts (sec. output)
N=Discharges per second from rotary gap
V^2=Volts (transformer secondary).

INDUCTIVITY VALUES FOR DIFFERENT DIELECTRICS

Dielectric	Inductivity Value. "K"
Air at Ordinary Pressure, Standard	1.0000
Manila Paper	1.50
Celluloid	1.555
Paraffine, Clear	1.68 to 2.32
Beeswax	1.86
Paraffine Wax	1.9936 to 2.32
Paraffined Paper	3.65
Resin	1.77 to 2.55
Petroleum	2.03 to 2.42
Hard Rubber (Ebonite)	2.05 to 3.15
Turpentine	2.15 to 2.43
India Rubber, Pure	2.22 to 2.497
Sulfur	2.24 to 3.84
Gutta Percha	2.46 to 4.20
Shellac	2.74 to 3.60
Olive and Neats-Foot Oils	3.00 to 3.16
Sperm Oil	3.02 to 3.09
Glass, Common (Low Frequency)	3.25 to 4.00
Glass, Common (Radio Frequency)	4.21
Mica Sheet, Pure	4.00 to 8.00
Porcelain	4.38
Quartz	4.50
Castor Oil	4.80
Flint Glass, Very Light	6.57
Flint Glass, Light	6.85
Flint Glass, Very Dense	7.40
Flint Glass, Double Extra Dense	10.10

CHAPTER IV.

Spark Gaps.

THE spark gap forms one of the most important parts of any oscillatory circuit, and this proves particularly so in radio transmitting circuits, where everything must be designed to realize the utmost efficiency. This means careful and scientific design at every turn, and it takes into consideration such important topics as the proper dissipation of the heat produced in the gap; the proper arrangement of the gap to give the desired tone, and a number of other vital points.

The part played by the spark gap in an oscillatory circuit is to allow the condenser in this circuit to charge to the required voltage, and then to break down and permit the charge stored in the condenser, to surge back and forth across the gap in the form of sparks, until all of its energy is dissipated. For several reasons the ideal spark gap would be one which would insulate perfectly, or be *non-conducting* during the time when the condenser was being charged, and conducting perfectly, while the condenser was discharging.

The nearer these requirements are fulfilled in any spark gap, the more efficient will this piece af apparatus perform its function. While the discharge is passing, the resistance of the gap depends upon two factors: the resistance increasing markedly with the length of the spark, and decreasing rapidly with the oscillatory current, amounting with a half-inch gap to several hundred ohms when a fraction of an ampere passes, and but a small fraction of an ohm when say sixty amperes flow across the gap. If the spark length is above one-half inch, the resistance with the same oscillatory current flowing, can be taken as approximately proportional to the spark length. However, in a condenser circuit, the quantity of electricity is stored up in the condenser, and in consequence, the amount of oscillatory current increases with the spark length. Hence, we find two conditions working against each other, as regards the influence of the spark length on the spark resistance. However, we can increase the amount of current passing through the gap without increasing the length of the spark, by simply increasing the size of the condenser, and the most efficient circuit for a given amount of power, is that in which there is a moderate spark length with a large condenser.

When the condenser has been fully charged, the gap becomes filled

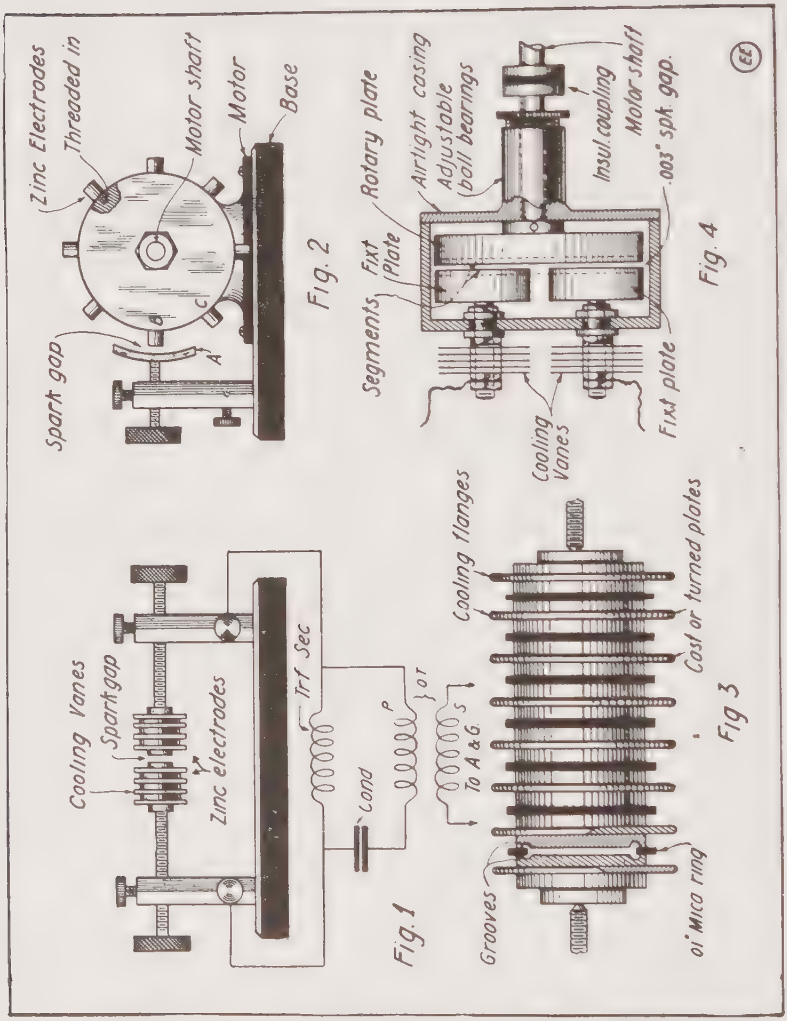
with metallic vapor, and for the time being forms a high frequency alternating-current arc. The conductivity of the spark is due to the presence of metallic vapor in the gap. After the discharge ceases, and if this metallic vapor is not quickly removed from the gap, the insulation will in consequence be very low at the time that the condenser is passing through its next *charging period,* which of course occurs in a small fraction of a second, usually.

It is therefore essential that we remove this vapor completely as soon as possible after the discharges of the condenser have ceased. This has been attempted in various ways in the past, such as by providing spark gaps having large cooling vanes attached to the spark electrodes, as in Fig. 1, and also by causing one or both of the spark gap electrodes to rapidly rotate, so as to constantly refresh the air in the gap. This latter condition, which is usually met by arranging a number of small spark electrodes on a rotary disc attached to the shaft of a motor, or to the shaft of a motor-generator in the case of synchronous spark gaps, the spark being caused to jump through the air between the constantly moving electrodes, and one or more fixed electrodes mounted on the base of the spark gap.

Fig. 2 shows a *non-synchronous* type of spark gap in which the speed of the rotating disc bears no definite relation to the frequency of the alternating-current in the transformer or spark coil. As a spark is apt to occur, at most any indefinite time, it is best with such non-synchronous rotary gaps, to provide a stationary electrode "A," in the form of a segment, having a pitch equal to the distance between two of the rotary electrode points.

For synchronous rotary gaps, driven by a synchronous A.C. motor or by mounting the disc on the same shaft with the motor-generator, as is done in the best types of commercial radio transmitting sets, the fixed electrodes need not be any larger than a single electrode point on the rotary disc.

One of the most efficient spark gaps used very successfully by commercial stations and also by numerous amateurs, is the *quenched* gap illustrated at Fig. 3. This gap, which is very well known today, is designed on several important basic principles. The foremost of these desideratums is that each gap shall be preferably not over 1/100 of an inch in length, and moreover, that the gap shall be absolutely air-tight. Further, not over 1,000 to 1,200 volts should be



Various types of wireless spark gaps.

applied to each individual gap, and for higher voltage a suitable number of these short gaps are placed in series, as shown in the illustration herewith: two gaps being adapted to 2,000 volts—three gaps to 3,000 volts, etc. The action of this gap has been described at some length in a semi-technical manner by Mr. Charles R. Ballantine in the March, 1917, issue of *The Electrical Experimenter.* Briefly, the action of the gap is based upon the fact that a small quantity of air is trapped between the spark surfaces separated by a mica ring of proper thickness. After the first few sparks have passed the oxygen in the trapped air is burned up, resulting in a partial vacuum in the gap. This conduces to the rapid quenching thereafter of the spark discharges, due to the condenser, and gives rise to a very ideal set of conditions for the entire radio transmitting circuit. This is because the oscillations in the spark gap-condenser circuit are cut off after the first few beats or sparks, but the oscillations induced in the aerial-ground circuit are left free to oscillate for a longer period. This prevents the reaction of free oscillations in the spark gap circuit upon the aerial or secondary circuit—a condition which is invariably found in ordinary radio transmitters fitted with a plain fixed spark gap, and a condition which mitigates seriously against the best efficiency of such an equipment. The quenched spark gap usually consists of a number of these small gaps as above described, which are placed in a suitable frame, so that considerable mechanical pressure can be exerted axially upon them, in order to make the gaps thoroughly air tight. For outputs above one-half K.W., the gap often becomes unduly heated, and it is common practice to place a small motor-driven blower or fan beside the gap, in order to cool it by carrying off heat from the cooling flanges.

At Fig. 4, we have what is known as a *rotary-quenched* spark gap. This particular design of gap has met with considerable favor, especially for small radio transmitters, of from one-quarter to several kilowatts output. This gap possesses the distinct and remarkable quality of producing a high-tone in the telephones at the receiving station, even though it is used on a low frequency or 60 cycle transformer at the transmitting station.

In the first place, this gap operates with a remarkably small clearance between its two semi-circular fixed spark electrodes and its rotary electrode, or having a gap about three-thousandths of an inch in length. The gap operates in an air-tight chamber formed by a

heavy metallic casting, which carries suitable cooling vanes, and besides which there are provided a number of auxiliary cooling vanes as shown in Fig. 4, at the rear of the gap. Being air-tight at the start, this gap operates in the same manner as the design shown in Fig. 3, known as the Telefunken gap. To obtain a high spark note with the rotary quenched gap of Fig. 4, the two fixed and also the rotary electrodes have their faces accurately machined or milled-out at equal distances, resulting in a number of teeth, between which the spark occurs. These gaps have to be built very accurately of course, as the gap itself measures about .003 inch, and it is desirable to have the sparking distances constant and similar. A typical gap of this class has the sparking surfaces and the copper on both stationary and rotary elements milled with thirty-six radial slots, so that when rotated by a small motor at 1,800 R.P.M., the resultant tone corresponds to that of a 540-cycle alternator. It is necessary that the width of the spark segments are so proportioned that sparks will occur during not more than one-half of the total time, as otherwise the telephone diaphragm at the receiving station is retarded in its excursion away from the magnet, thereby resulting in a decrease in the sound intensity.

[Those interested in this spark gap will do well to look up the matter in the excellent paper by Mr. Melville Eastham, entitled "The High Tone Radio Telegraph Transmitter" in the December, 1914, issue of the proceedings of the Institute of Radio Engineers—Author.]

CHAPTER V.

Radio Transmitting Inductances.

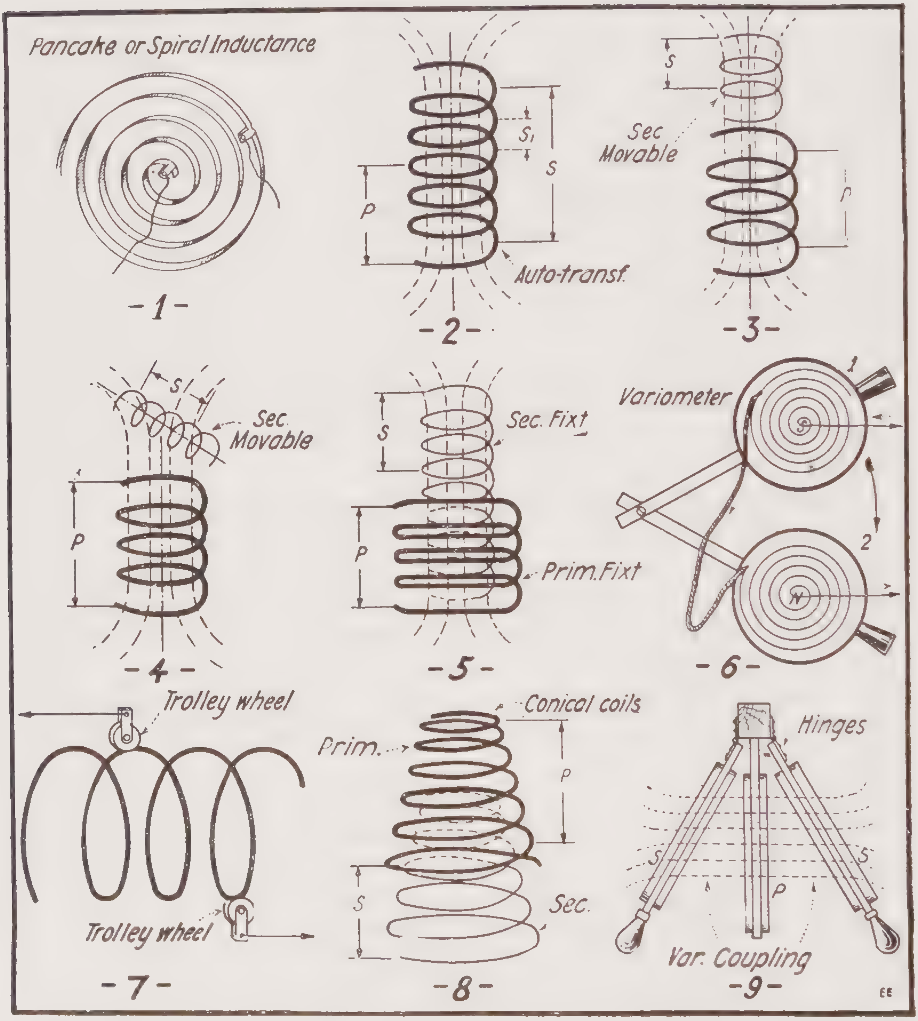
RADIO transmitting inductances are of several types. The principal characteristic of this particular piece of apparatus is that it invariably has an "air" core, in contradistinction to the ordinary alternating current inductance, which is most always provided with a laminated iron core.

The difference between these two forms of inductance, as just described, is due to the fact that the frequency is so high in radio oscillatory circuits that iron cannot be efficiently used for several reasons. There may come a day when we shall have radio inductances with iron cores, but up to the present time it has not been found practicable to provide them, even though there is a very large loss due to the electro-magnetic induction which has to take place through air which, as is well-known, is a very poor conductor of magnetism. Magnetic induction in iron at radio frequencies and in such circuits as these tends to lag behind the rapidly changing current, and results in a very low power factor; besides producing a high loss due to hysteresis.

We will take up in this chapter several types of tuning inductances used in radio transmitting circuits, and which have been adopted in actual practise. Fig. 1 shows what is known as the "pan-cake" or spiral inductance. This is a very effective form, particularly when wound of flat copper ribbon. It is sometimes built of heavy round wire, but the flat ribbon of course gives the most efficient results. Spring clips are provided with practically all inductance coils of these types, so that any part thereof may be included in the circuits to which they are connected.

The inductance illustrated in Fig. 2, comprises what is known as an *auto-transformer*. In this case a single winding serves as both primary and secondary. The primary circuit being connected across at P, and the secondary circuit connected across the clips at S or Sl, etc. It is possible to vary the coupling between the primary and secondary circuits to some extent with such a transformer, by connecting one of the circuits to the position Sl (*i.e.*, widely separated), for instance, as related to the second circuit at P.

The dotted lines running axially in the diagrams here shown indicate the magnetic field set up when current passes through the coil, and the action of the auto-transformer becomes evident from Fig. 2,



All of the Principal Types of Radio Transmitting Inductances Are Illustrated Above. The Peculiar Characteristics of Each One Are Explained in the Accompanying Text.

as it will be seen that all of the turns in the coil are threaded or cut by magnetic flux created in it. Thus it is possible to increase the potential of a circuit with a single winding as shown. When potentials are to be increased by auto-transformers, the ratio between primary and secondary voltages is usually not greater than 3 to 1 or 8 to 1.

Diagram Fig. 3 shows the simplest form of *loose-coupled* oscillation transformer for transmitting circuits, and which comprises a helix P, into which a smaller coil S, or secondary, may slide. The spark gap circuit is usually connected to the outer coil or across the clips P, while the aerial and ground connections are made to the movable secondary coil S. In any case, the number of turns, or fraction of a turn, in either circuit are adjusted, with a hot-wire ammeter connected in the ground lead, until a maximum radiation current is obtained. Of course, the wave length must be checked on a wave meter, or else computed, but the wave meter method is always preferable. The action of this two-coil oscillation tuning transformer is evident from the illustration Fig. 3, where it is seen that the magnetic flux lines from coil P, cut across the turns of the secondary coil, even though the coils are often quite widely separated.

Maximum coupling is obtained when the secondary coil is all the way within the primary coil, and vice versa. A unique type of transmitting inductance having two coils, one for the secondary and one for the primary, is shown at Fig. 4.

This type has found much favor in commercial radio circles, and works very efficiently when it is properly related to, and designed for use with a certain type and size transmitting set. The primary coil which is usually the larger one is shown at P, while S, or the secondary coil, is rotatably mounted in a fixed axial position above the primary. The degree of coupling is thus variable and the amount of inductance in either circuit is adjustable as in other types of transformers; *i.e.*, by changing the numbers of active turns in circuit. The position for maximum coupling with this oscillation transformer occurs when the secondary and primary coils are placed in the same axial relation; when the secondary coil is rotated 90 degrees, or in a position at right angles with respect to the primary coil, a position of minimum coupling is obtained. The magnetic flux field is shown by the dotted lines as in the other diagrams.

There is another form of two-coil oscillation transformer which has been used quite extensively in commercial radio work as well as in experimental and amateur stations, and this is illustrated at Fig. 5.

Here the secondary as well as the primary windings are fixed and mounted upon a stationary frame. Considerable variation in the coupling can be obtained by causing the secondary active turns to be at the upper end of the fixed secondary winding, while the active primary turns are caused to be at the lower end of the fixed primary winding, and vice versa.

One of the easiest ways of making a two-coil oscillation transformer is based upon this principle, and necessitates the cutting out of one turn, about two-thirds the way down on any ordinary transmitting helix. This results in two distinct windings being formed, as becomes evident; the shorter winding being used as a primary and the longer one as a secondary. The clips can be moved along the coils to vary the coupling as aforementioned.

Fig. 6 shows what is known as the transmitting *variometer*. It is usual to build these non-adjustable as to turns, and the inductance of the instrument is varied by simply moving the two spiral coils nearer to each other or farther apart, as the case may be. When the two coils are brought parallel on the same axis, and when connected as shown in the diagram Fig. 6, then the minimum inductance is obtained for the reason that one coil "bucks" the other or the inductance of coil (2) neutralizes that of coil (1). When the coils are drawn completely apart, their maximum inductance is obtained. The variation of inductance by this means is quite precisional, and the "Telefunken" radio sets utilize this tuning principle to a very large extent.

At Fig. 7 is shown the method of making a continuously variable contact with transmitting inductances. This trolley wheel contactor was first used on Fessenden radio inductances. Some of these, in the larger sizes are built of hollow copper tubing, through which water runs to carry away the heat, and it is interesting to note in this respect that a hollow tube is fully as efficient as a solid rod, size for size, in radio transmitting inductances. This is so for the reason that the current at these high frequencies, varying from 50,000 to 300,000 cycles or possibly more per second, only penetrates a very slight distance from the surface, due to what is known as the "skin effect." This is the reason why radio transmitting sets are best hooked up

with either woven wire ribbon or with a substantial flat copper strip, instead of with a small size round copper wire.

The conical tuning inductance shown at Fig. 8 has come much into favor, during the past few years, and provides one of the most efficient forms of radio frequency inductance. The primary as well as the secondary coils are made in conical form as shown, and the coupling is varied by sliding one within the other in the usual manner. The number of turns and the position of the active turns in use in any case is adjustable, as in the previous examples.

The principal advantage of this form of inductance coil is that when a small amount of inductance is required only, the operator has the privilege of selecting a number of smaller diameter turns instead of using one or two turns of large diameter, which is less efficient owing to the low flux density in this case. There are several other desirable factors involved in the design of conical inductances, such as the rise in potential by auto-transformer action and means for distributing this more effectively, and the fact that a larger inductance variation in a given space can be obtained, all things considered.

Conical oscillation transformers have been utilized with great success by the National Electric Signaling Company. The advantage of this type of oscillation transformer is that a finer and closer mutual inductance can be obtained, since the movable coil can be placed in closer proximity with that of the stationary one.

One of the most efficient methods of arranging an oscillation transformer, and involving the use of three "pan-cake" inductances is shown at Fig. 9. Usually the center coil or "pan-cake" is connected as the primary, while the two outer movable "pan-cake" coils are connected in series and form the secondary. As the dotted lines indicate, the flux distribution with this arrangement is the most efficient in that both of the secondary coils are in active use in a strong field in contradistinction to the usual oscillatory transformer of this type, utilizing but two "pan-cake" coils, in which case the coil acting as the secondary is cut by only one-half the flux that this one is.

CHAPTER VI.

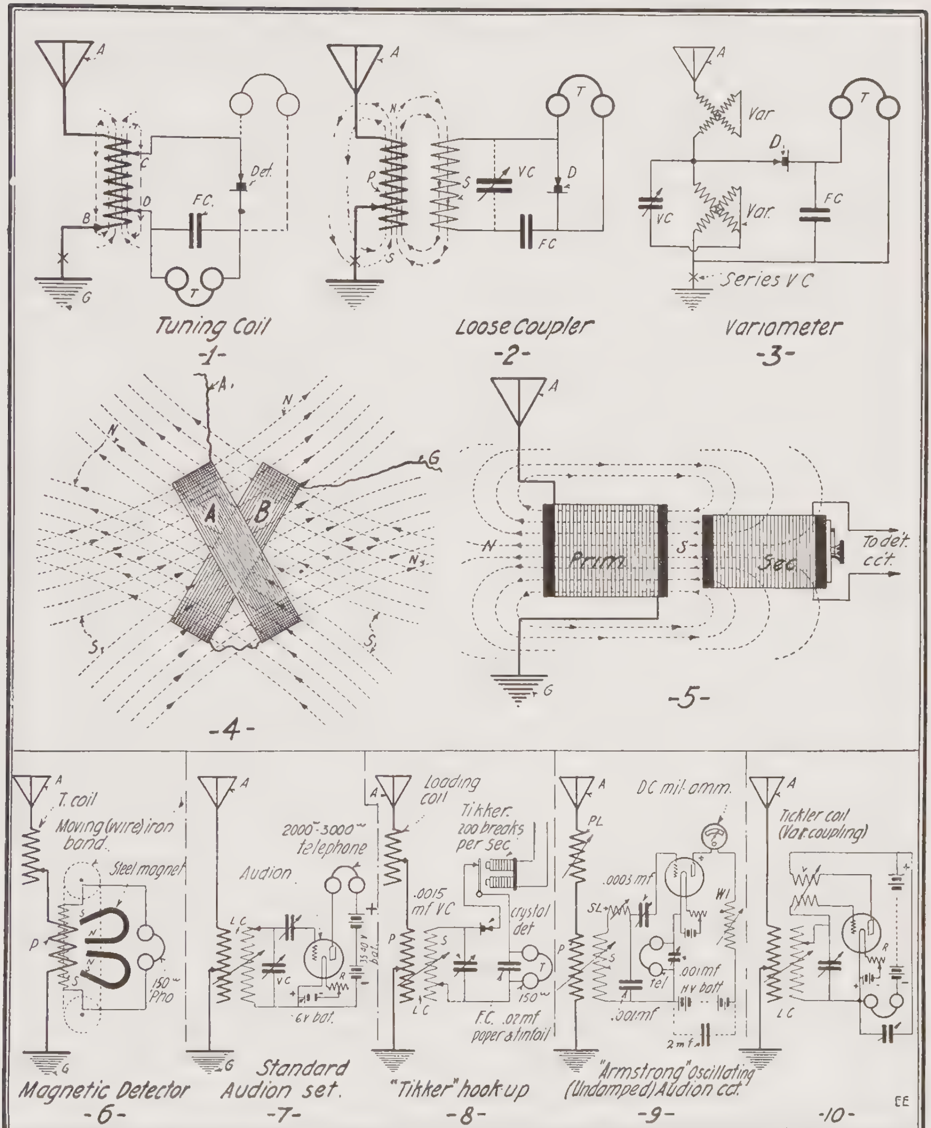
RADIO RECEIVING TUNERS.

THE tuning for incoming radio messages is accomplished through some form of inductance coil or coils. The simplest tuned circuit involves the use of a *tuning coil;* as shown in Fig. 1, this comprises a single layer of wire wound on a hard rubber, fiber or other suitable insulating tube and which has an air core. The number of turns in use at any time is adjustable by virtue of movable sliders or else by multi-point switches connected up to equally spaced sections of the coil.

The hook-up, Fig. 1, shows what is known as an *auto-transformer* connection; *i.e.,* the single coil acts as both primary and secondary simultaneously. The aerial tuning circuit is formed through lead-in, inductance, slider B, and so to ground. The closed oscillating or detector circuit is composed of the detector, slider C, inductance between C and D, slider D, and fixed condenser F.C. The telephone receivers are shunted across the fixed condenser. The 'phones are sometimes connected across the detector as indicated by the dotted lines. The former hook-up is usually preferable, especially where the capacity F.C. is variable, either gradually or in steps. The magnetic field set up within the inductance coil is shown by the dotted lines. It is possible to obtain higher or lower potential in the detector circuit CD, as compared with that existing in the primary by simply arranging the sliders C and D to embrace more or less turns than are in use in the primary circuit at any instant. High wave lengths are tuned in by connecting a variable condenser across the secondary sliders C and D, and also in some cases across the aerial and ground inductance terminals, depending upon the amount of inductance and capacity in the antenna. To tune in short waves, shorter than the fundamental period of the antenna circuit, it becomes necessary to insert a variable condenser in series with the ground lead as indicated at X. This reduces the capacity of the aerial circuit in accordance with the formula for the joint capacity of two or more condensers connected in series:

$$C_j = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2}};$$

where Cj is the total or joint capacity and C_1 and C_2 are the respective capacities connected in series.



Different forms of radio receiving tuners, loose couplers and loading coils.

The received signal current taken off in the detector circuit at C D passes through the crystal or other detector and fixed or *blocking* condenser as shown. The crystal detector acts as a rectifier of the high frequency incoming oscillations, and the signals are heard in the 'phones.

Fig. 2 illustrates a two-coil coupling transformer or *loose coupler* as it is called in radio parlance. The primary winding is connected to aerial and ground, and is thus energized by the aerial oscillations. The oscillating magnetic field thus set up induces a similar current in the secondary which acts upon the detector and 'phones. Usually, a variable condenser is connected across the secondary coil to enable the operator to tune this circuit in syntony with the primary oscillatory circuit, with regard to frequency and wave length.

Fig. 3 shows a typical receiving circuit employing two *variometers;* one in series with the aerial lead-in to act as a *loading coil,* the other acting as a means of transferring the aerial circuit energy to the detector circuit in the manner apparent.

The variometer is a very efficient tuning instrument and acts upon a unique principle. This action is outlined at Fig. 4. Simply expressed, the variometer changes the inductance in the circuit by the reaction between the magnetic field of the primary and secondary. The complete variometer comprises two short cylindrical coils (sometimes spherically wound) with the inner and smaller diameter coil pivotally mounted within the larger stationary coil. The inner coil is connected in series with the outer one and can be revolved about its axle through 180 degrees. Now, when in one concentric position, the two coils are connected so that their magnetic fields *oppose,* the inductance of the variometer is practically zero. If the inner coil is then turned on its axle, the inductance will gradually increase and maximum inductance is obtained when the inner coil has revolved 180 degrees; *i.e.,* when this coil has completely changed sides with respect to the outer coil. This effect is readily understood from the diagram Fig. 4. The dotted lines show the magnetic field due to the outer coil "A," as well as the resultant electro-magnetic field produced by the inner coil "B." As becomes evident in the relative position of the two coils here shown, a considerable portion of the North and South magnetic field due to coil "A" is neutralized or counteracted by the South and North poles of coil "B." When coils "A" and "B" are turned until their

faces align with their N. and S. poles coinciding, then it is seen how the one magnetic field will completely neutralize the other and minimum inductance will be had in the instrument. Theoretically considered, if coil "A" produced a magnetic flux density of 1,000 gausses per square centimeter of core section, then if this was opposed by 1,000 gausses of flux per square centimeter, of *opposite* polarity, the resultant magnetic flux, reacting on the coils will be zero. If the flux of 1,000 gausses per square centimeter of coil "A" is aided by the *like* flux due to coil "B," then the resultant flux acting on the coils will be 2,000 gausses per square centimeter.*

Fig. 5 shows how the so-called *loose coupler* transfers the antenna circuit oscillations to the detector circuit by electro-magnetic induction. The farther the secondary coil is separated from the primary the smaller the number of flux lines linking the secondary turns, and the less the mutual induction between the coils. With the secondary coil all the way within the primary, the strongest signals will be heard usually, but owing to interference from other stations, static, etc., it is often found in practise that the signals are heard best with a relatively loose coupling, or with the secondary considerably removed from the primary. At the Sayville, L. I., station, signals from Germany have been received with 2 to 4 feet of coupling separating the primary and secondary. The coupler coils were quite large of course, or about 20 inches long. The September, 1917, issue of the *Electrical Experimenter* contained the rules and formulas for designing both large and small loose couplers.

Loose couplers, as well as tuning coils, variometers, etc., should preferably always be designed to handle the wave lengths to be tuned in. If the range of frequency is quite large then two loose couplers forms the best solution of the problem; a small one for short and medium wave lengths and a large one for higher wave lengths. Loading coils, generally speaking, are a source of loss and are to be avoided. They offer considerable resistance to the weak antenna currents and cannot transfer energy to the detector circuit, except in-

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*[For calculating the inductance of both long and short single layer as well as multilayer radio coils, reference should be made to Chapters 13, 14 and 15 of this book, entitled the "*Calculation and Measurement of Inductance.*" See also "Wireless Telegraphy and Telephony Hand-Book," by Dr. W. H. Eccles; "The Calculation and Measurement of Inductance and Capacity," by W. H. Nottage, B. Sc.; Bulletin of the Bureau of Standards, Vol. VIII, No. 1, page 64, for formulae covering the calculation of self as well as mutual inductance.]

directly, such as by bringing the aerial or open oscillating circuit into resonance with the incoming wave. This, of course, causes a maximum flow of energy through the antenna circuit, which, under many conditions, will effect a sufficient transfer of energy to the detector circuit to operate the responsive devices therein. This explains why the erstwhile Radio Amateur was forever building gigantic *loading coils.* He had found that his fellow "Radio-bug" could hear "Nauen" or "Honolulu" on his receiving set consisting of an 800 meter loose coupler coupled up with a *loader* made of a cardboard tube 9 feet long, wound with a mile or so of No. 36 silk covered magnet wire. He heard these far distant stations not because of good tuning conditions but rather in spite of poor tuning; this was often due also to the superior sensitivity of the Audion or other amplifier used, over which he exercised no control.

This argument is the same as that for charging 6 volt storage batteries with a bank of lamps (or a rheostat) from a 110 *volt* circuit. If you are going to charge the 6 volt battery in that way, well and good; but don't forget that the energy expended in lighting up the bank of lamps is forever wasted and it does the battery no good whatever. The moral is—use a low-voltage charging dynamo, driven by a water wheel or small engine, or a well designed rectifier if alternating current is available. Likewise, if long waves are to be tuned in, use a large enough loose coupler and put all of the energy to work. For short or medium ranges, a loading coil is often satisfactory because of the superior strength of signal received.

Diagrams Figs. 6, 7, 8 and 9 illustrate four of the principal tuning schemes in use today for receiving radio signals. Figs. 6 and 7 for the reception of damped waves and Figs. 8 and 9 for interpreting undamped wave signals, such as sent out by stations employing the Poulsen arc or a Goldschmidt (or Alexanderson) radio frequency alternator.

Fig. 6 outlines the connection of the Marconi *magnetic detector.* It is tuned in either by a tuning coil in series with the aerial or it may be connected in the secondary circuit of a loose coupler. It is connected in the tertiary circuit of the Marconi multiple tuner, the fixed or blocking condenser being variable and the tertiary winding of low resistance; *i.e.,* wound with relatively coarse wire. Low resistance 'phones (75-80 ohms each) are used with this detector.

Fig. 7 is the hook-up for a standard *damped* wave Audion receptor. The loose coupler secondary should have high resistance; *i.e.*, many turns of fine wire, so as to give a relatively high potential, as this detector is a potentially operated type. It is remarkably sensitive and many times more efficient than any form of crystal detector. High resistance 'phones are used with this layout of apparatus, and the battery polarities should be watched carefully.

Diagram Fig. 8 shows how the Poulsen *tikker* should be hooked up for receiving *undamped* wave signals. In one instance, cited by deForest, the tikker (interrupter) made from 150 to 200 breaks per second (the tone is regulated by the tikker speed); the 'phones comprising two ordinary 75 ohm receivers in series were shunted by a paper and tinfoil condenser of .02 microfarad. The same authority also found that a crystal detector could be used, as shown in diagram, if desired, but that while it raised the pitch of the incoming signals, it also reduced the strength of the signals on long ranges. A buzzer or gold wire tikker is indicated here, but the Poulsen stations now use a rotary wheel tikker, driven by a motor. A light spring wire brush rests in a groove filed in the perifery of the revolving disc. The action of the tikker is to allow the radio frequency energy to pile up in the large capacity connected across the secondary of the loose coupler; this periodically discharges into the condenser connected across the 'phones and which capacity in turn discharges through the 'phones.

Diagram Fig. 9 shows a regenerative hook-up for a single Audion, whereby damped as well as undamped signals can be received.

The layout in Fig. 9 consists virtually of a loose coupler, primary and secondary loading coils and three variable condensers connected to an Armstrong circuit. The dimensions of the inductance coils are as follows: Primary of coupler is 10 x 5 inches and is wound with No. 22 S. S.; the secondary is 10 x 4¼ inches, wound with No. 28 S. S.; the secondary loading coil SL is 22 x 3½ inches and wound with No. 30 S.S., while the wing inductance WI has No. 30 S.S. for its winding. The capacity of each condenser is given in the diagram.

An aerial successfully used with this set measured 600 feet long, the wires starting 10 feet apart and ending 18 inches apart (fan shaped), the average height being about 50 feet. With this set it was possible to tune to 4,000 meters without any aerial inductance coils, and if loading coils are connected in the circuit it became possible to receive stations of over 9,000 meters wave length.

A simple Audion regenerative circuit, especially suitable for amplifying spark signals of wave lengths above 200 meters is shown in Fig. 10. The additional or *tickler* coil is a small auxiliary inductive coupler and connected as shown. It is used to interlink magnetically the wing and grid circuits. Remarkable amplification is obtainable with this scheme. It is being more widely adopted every day in commercial practise and the Army and Navy receiving sets are fitted with the tickler coil arrangement. The U. S. Navy specifications call for it. The superiority of the variable coupling tickler coil is that the device will always respond in a regenerative manner, while the circuit shown at Fig. 9 is more or less dependent upon certain critical conditions in the circuit for its successful operation. The hook-up shown at Fig. 10 is adapted to the reception of undamped as well as damped (spark) stations.

CHAPTER VII.

Radio Receiving Condensers.

PRACTICALLY all modern radio receiving sets employ some form of condenser or capacity, either in the form of a definite fixed capacity or else in the form of a variable or adjustable capacity. The aim of this chapter is to describe in detail the principal types of condensers found in modern radio receiving apparatus, as well as their use and connection in these circuits.

Referring to the diagrams herewith, Fig. 1 shows how fixed and variable condensers are represented in diagrams and hook-ups of radio receiving apparatus; Fig. 1-A showing a fixed condenser and B, a second way of representing a fixed condenser, while C shows how a variable or adjustable capacity is indicated, viz., by drawing an arrow through the two plates diagonally. Fig. 2 illustrates the construction of simple fixed and variable condensers. Fig. 2-A illustrates the construction of the simplest form of fixed condenser, having a dielectric C, charged by means of two tin-foil or other conductive plates A and B. The metal charging leaves placed on alternate sides and in contact with the dielectric are always cut somewhat smaller than the insulating medium, to prevent leakage, and the possible chance of short-circuits. The small fixed condensers found in a great many radio receiving sets are made up of from ten to fifteen paraffined paper sheets, about two by three inches, interleaved with alternately charged tin-foil leaves. Every other tin-foil leaf is connected to a common terminal, as at "A," while the balance of the alternate metal leaves are connected to the opposite terminal "B."

Before going any further, it is well to note that the metal charging plates or leaves of any condenser merely serve to distribute the electric charge from either terminal to the insulating medium, called the *dielectric,* and this dielectric is the member that retains the charge, and *not* the metal electrodes. This being the case, and as becomes evident, the capacity of any condenser depends upon the coefficient of electrostatic induction of the dielectric. This factor is generally called the "specific inductivity" of the material used as the dielectric, and as a basis to work on, air is taken to have a specific inductivity of 1 at standard atmospheric pressure; the inductivity of any other substance is measured by the ratio of the capacity of a condenser, when its plates are separated by that substance, to the capacity of

the same condenser when its plates are separated by the same thickness of dry air.

This specific inductivity factor is also known as the "K" value of the dielectric. Any electrical or radio text-book contains a table of the various insulating mediums used as dielectric in building condensers and the corresponding "K" values. A table of these values appeared in Chapter III, where the necessary formulæ for computing the capacity in micro-farads of any condenser are given.

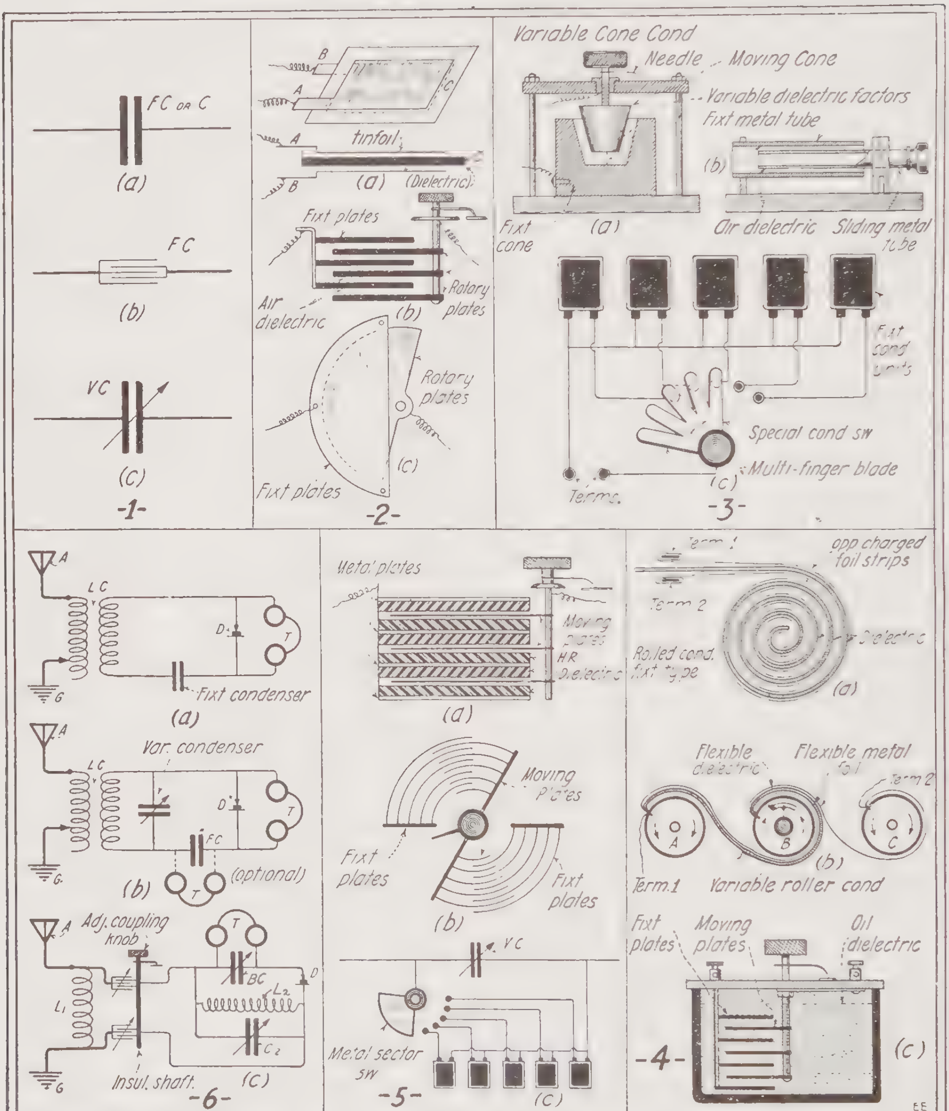
Resuming, Figs. 2-B and C illustrate in a simple manner how a rotary, variable, air dielectric condenser is constructed. A central rotary knob and shaft have rigidly mounted thereon one set of semi-circular plates, which may be turned so as to inter-leave with a corresponding number of fixed or stationary semi-circular plates. The condenser is provided with a scale which is sometimes calibrated to read in m.f., direct, or else a calibration curve is supplied with the instrument. Low-priced condensers are not usually calibrated, but the capacity may be computed for any position of the rotary plates by means of the usual formulæ. One terminal leads to the fixed plates, while the second terminal leads to the rotary plates of this type of condenser, and in fact this applies to all other similar types of variable condensers. A variable condenser of the *moving cone* type which has been used considerably in laboratory work is illustrated at Fig. 3-A. This condenser involves the use of male and female conical members, arranged in the manner indicated, so that the inner cone can be raised or lowered by a precision screw adjustment, and the distance between its end and the bottom of the conical chamber of the fixed electrode, as well as the thickness of the air space surrounding the small cone can be varied, and likewise the capacity. Another simple form of variable condenser which has been used extensively in various types of receiving sets, both domestic and foreign, is shown at Fig. 3-B and utilizes one fixed and one sliding brass member, or other non-magnetic metal tubes. The sliding tubular member is sometimes provided with an indicating needle which reads over a scale secured to the base of the instrument. This condenser has a fixed thickness of dielectric, but the length of the active condenser insulation is variable to quite a fine degree.

Fig. 3-C shows what is commonly known as an "adjustable condenser." In this form of condenser the capacity is varied by means of a special switch provided with a multi-fingered blade, so that the

capacity of each unit switched into circuit is retained as each successive unit is switched in.

Several other forms of condenser are illustrated in Fig. 4-A, B and C. That at A is the familiar rolled type of condenser. These are formed of one or more dielectric layers, made long with respect to their width, and which are suitably interleaved with two or more metal charging leaves; the whole is then rolled up and tightly compressed after having been soaked in hot paraffin wax. This gives a high capacity in a small space, and enables a large capacity condenser to be quickly constructed. Substantial terminals for such a condenser are formed of small copper strips about 1/4 of an inch wide, which are wrapped in several turns of the tin-foil leaf at the end as Fig. 4-A indicates; this junction may be riveted. Where a fixed tin-foil and waxed paper condenser is used, and there are a large number of tin-foil tabs to be joined together, a very efficient and substantial connection is afforded by simply punching or drilling a hole through the tabs and passing a battery terminal screw through the opening formed and placing on either side of the tin-foil tags a piece of copper or brass about 1/2 inch square. When the nut on the screw is tightened up, the tin-foil connections will be clamped firmly, and the connecting wire from the circuit may be fastened between two nuts on the screw or else soldered to the screw as desired.

An interesting *roller type* of variable condenser was invented some years ago by Mr. H. Gernsback, and this is shown schematically at Fig. 4-B. Three porcelain rolls are used in this scheme A, B and C. The three rolls are geared to each other by means of gears secured to the shafts of each roll, but which are not shown for the sake of clearness. A thin as well as flexible sheet of copper or aluminum foil, as well as a strip of flexible insulation, such as oiled linen or oiled silk is secured to roller A at the left. These are also secured to roller B as shown, and a second strip of flexible metal foil makes connection to rollers B and C. When the adjustment knob secured to the central roller B is turned, it unrolls the dielectric and one copper electrode from A, and also the second copper electrode from C, while a gradual increasing condenser capacity is produced about the perifery of roller B. The arrows in the drawing indicate how the rollers turn when the central knob attached to B is rotated either to the right or to the left, increasing or decreasing the capacity in consequence.



The principal types of radio receiving condensers are here illustrated in detail and also connected in circuit.

The diagram at Fig. 4-C shows how a variable air dielectric condenser may have its capacity increased several fold by filling its container with oil. One of the best oils to use for the purpose is castor oil, which has a "K" value of approximately 5. Thus, if the variable condenser with air dielectric has a capacity of .001 m.f., when it has its container filled with castor oil, its capacity will be increased to about .005 m.f. This property is made use of considerably in the laboratory, either for the purpose of increasing the capacity of the condenser or for increasing the resistance between the plates, and thus cutting down brush discharges and other leakage, where it is desired to use such a condenser in experimental *Poulsen Arc* circuits, etc.

A special form of high capacity, small size rotary variable condenser used by one of the leading commercial radio companies in their receiving sets and measuring instruments, as well as wave meters, is shown in section at Fig. 5-A. This variable condenser has about five times the capacity of an equal size air dielectric condenser, for the reason that it employs hard rubber as a dielectric instead of air.

The stationary semi-circular plates are covered with thin discs of hard rubber as illustrated, and the moving semi-circular plates slide in between the hard rubber leaves in the usual manner. The reason for the greatly increased capacity of this type of condenser is due to the high specific inductivity of hard rubber, which is about 5. Another interesting form of condenser which has been used both in this country and abroad to some extent, but which must be built very accurately to be reliable and free from accidental short-circuits, is the vertical, cylindrical plate condenser illustrated in plan view at Fig. 5-B. As becomes evident the central rotary knob and shaft carries a suitable rigid member to which is fastened at either end a set of properly spaced, cylindrically curved plates which, as the knob is turned, intermesh with the similarly curved stationary plates, and thus increase the capacity of the condenser until they are moved through 90 degrees. The capacity is reduced by turning the knob so that the moving plates slide out from within the fixed plates.

It is often desirable in building wave meters and in certain forms of receiving sets to obtain an extra high variable capacity. A common method of accomplishing this result is indicated at Fig. 5-C. A small or medium size variable condenser VC, is connected in series with the circuit, and in shunt with this variable capacity there is placed

a group of small fixed condensers of the desired capacities, arranged with a multiple-contact switch similar to that shown in Fig. 3-C or one comprising a metal sector as shown at Fig. 5-C with a series of spring contact fingers. Thus suppose the variable condenser VC has a capacity of .001 m.f., and that each one of the five fixed capacities shown has a similar m.f. value. It is thus clear that we may now obtain any capacity from practically zero up to and including .006 m.f. by intermediate stages.

The standard connections for both fixed and variable condensers are given at Fig. 6-A and B. A fixed condenser is usually connected in series with a detector as shown at Fig. 6-A, and is sometimes called the "stopping" condenser. The high resistance telephone receivers used with this circuit in connection with a crystal detector D, are frequently shunted across the fixed capacity as at Fig. 6-B. Either connection of the telephone receivers serves equally well in a majority of cases, but if the capacity across the 'phones is adjustable or variable, it is considered best practise to connect the 'phones across it instead of the detector, as considerable tuning can be done in this way and maximum strength of signal obtained.

Referring to Fig. 6-B, a standard connection of the variable condenser is across the secondary of the loose coupler LC. The variable capacity thus shunted across the secondary not only permits the closed oscillatory circuit to be adjusted to resonance with the open aerial circuit, but also permits a closeness of adjustment or tuning which the usual secondary inductance switch does not give. In any case the oscillations set up in the secondary circuit by adjusting it to resonance with the aerial oscillatory circuit, overflow to the shunt detector circuit, where part of the current is rectified by the crystal detector D, indicated in the diagram, and is stored up in the fixed condenser. The charge which this fixed condenser accumulates during the time of a single train or *group* of oscillations, discharges through the high resistance telephone receivers T, thus causing the diaphragms of the 'phones to vibrate at a rate which corresponds to the *spark frequency* of the transmitting station.

A new use for variable condensers is shown at Fig. 6-C. They are here used in the rôle of a *capacity coupling* between the aerial and closed oscillatory circuits. The diagram shown is that described and illustrated in the "Naval Electrician's Text-Book" by Admiral Bullard, Volume 1. This arrangement of capacity coupling in the

place of *electro-magnetic coupling,* which is used in practically all other receiving sets, is strongly commended by the U. S. Navy experts, and is claimed to be equally efficient to any form of electro-magnetic coupling for short wave lengths, and to be very much higher in efficiency for long wave lengths. In this hook-up, devised by Dr. Louis Cohen, formerly of the Bureau of Standards Radio Laboratory, the primary circuit is tuned to the incoming wave length in the usual manner. The secondary coil L-2 and condenser C-2 are made resonant to the same wave length. The aerial circuit energy is transferred from the one circuit to the other by means of the two *coupling condensers* shown and which are secured to a common shaft, so that they are simultaneously adjusted. These condensers are in no sense of the word tuning condensers, and do not vary the adjustments of either primary or secondary oscillatory circuits. They are used for no other purpose than that of transferring *electro-statically* the energy in the aerial circuit and circulating through inductance L-1, thence to the closed circuit comprising inductance L-2 and variable capacity C-2, across which is placed an adjustable *stopping* condenser BC, crystal detector D, and high resistance telephones, T.

CHAPTER VIII.

DETECTORS.

IN all modern radio receptors, especially in those sets used by the army and navy, the *detector* is one of the most important parts of the whole equipment. It has been developed and refined until at the present time it is quite a respectable instrument so far as its efficiency is concerned. The detectors now in use classify broadly into three groups, viz: mineral rectifiers (without battery); mineral rectifiers (with battery), and vacuum valves. Each class of wave interceptor and translator seems to fulfill certain requirements best. Where the vacuum valve would prove too sensitive and delicate, as in mule pack sets, etc., the mineral type detector proves best. Where the radio set is subject to fair treatment the vacuum valve or Audion detector proves feasible. For trench and field work the mineral detector is pre-eminently the type to use; it is at once rugged, simple in operation, always reliable, easily repaired, and last but not least, it requires no battery. An Audion detector is, on the other hand, liable to breakage, disarrangement of the electrodes, requires frequent adjustment, and must always have a fresh battery to light the filament, besides a 40 to 60 volt dry-cell battery for the wing circuit.

The minerals most in use as rectifiers of the high frequency oscillation groups are the following: Steel point-carborundum, gold or steel point-silicon, gold or steel point-iron pyrites, metal or graphite point-galena, zincite-chalcopyrite, silicon-arsenic, silicon-antimony, and "cerusite." There are a host of others, of course, but these are the principal ones being used on army and navy sets today. Some of the minerals are best known under their trade names—as "Perikon," "Pyron," "Radiocite," etc.

As aforementioned, radio investigators have devised may different forms of detectors, most of which *rectify* the high frequency antenna currents, *i.e.*, change them from alternating to direct or uni-directional impulses by some kind of valve action, thus rendering them capable of operating the telephones at an audible frequency. This rectification process is shown graphically in Fig. 1, at A, B and C. Curve A shows several damped wave trains such as received on a radio antenna; curve B delineates these wave trains rectified by the detector so that the current is allowed to pass only in one direction, while the graph C denotes the form of current pulse passing through the tele-

phones, where the rectified current is smoothed out by the inductance of the telephone receiver windings. Thus it is seen that what the operator hears in his head 'phones is not the high frequency aerial oscillations, but a rectified pulsatory current having a (group) frequency corresponding to the frequency of the current charging the condensers at the transmitting station. If it employs a 500 cycle alternator, then the operator at the receiving station hears a 500-cycle note in his head 'phones, etc.

As to the hook-ups used with the mineral detector, let us glance at Fig. 1. This shows how a *non-battery* mineral, such as galena, iron pyrites or silicon, is connected up in a simple tuned circuit comprising aerial, tuning coil TC, and ground. A high resistance pair of 'phones is invariably used in such systems, connected either across the detector or the fixed condenser as the dotted lines indicate. Fig. 2 illustrates how the *battery-using* mineral is commonly hooked up with a potentiometer having several thousand ohms. A better form of circuit and now used in the Signal Corps outfits is shown at Fig. 3-A. Here the current passes around through the secondary of the loose coupler. Three volts (2 dry cells) is usually the potential applied across the terminals of the potentiometer. The potentiometer slider (or switch) is adjusted until the maximum strength of signal is heard in the 'phones. Also the direction of the current through the mineral is important and it is well to provide a pole-changing switch in the battery circuit so that the current can be reversed through the detector. The mineral is usually connected to the negative battery line.

The *Perikon Detector* was developed by Dr. G. W. Pickard. This detector consists of two crystals—copper pyrites ($Cu\ Fe\ S_2$) and zincite (zinc oxid ZnO), held in firm contact against each other in the manner shown. The copper pyrite crystal is mounted in a cup mounted on a spring-actuated rod provided with a suitable knob, by which it can be swung in any direction. Zincite crystals are mounted in a large cup containing several pockets, the mounting of both of the minerals being effected with a low fusing solder, Wood's metal or Hugonium alloy. The action of the Perikon detector is supposed to be based on the rectifying principle previously described; that is, it will pass current in one direction but not in the other, and thus the incoming radio frequency oscillating (alternating) currents in the aerial are rectified and caused to give a sound in the high resistance 'phones connected to the detector. This detector is invariably used

with a battery of about two cells and the potential applied regulated by a potentiometer. When using a battery the polarity of the current must be such that the positive wire is connected to the copper pyrite crystal.

Diagram Fig. 3 shows the simplified connections for a "Radioson" (sealed-point) electrolytic detector, the 'phones serving as a potentiometer resistance. The sealed-point containing the fine Wollaston wire is made positive. No adjustment is necessary with this detector. Two dry cells are used, a switch being provided as shown. The electrolytic detector is extremely sensitive and can be made up in a few minutes in emergency. It does not "jar out."

The *Bare-Point Electrolytic Detector* has been the subject of much discussion among radio men as to who really was the basic inventor of it. But most writers of the day give credit, jointly, to Dr. Michael I. Pupin (1899), Professor Reginald A. Fessenden (1903) and W. Schloemilch (1903).

The action of this detector is based upon the fact that if an extremely fine platinum wire, measuring a few ten-thousandths of an inch in diameter is allowed to partially immerse its extremity in an acid solution (such as one composed of five parts water and one part nitric acid) that an incoming Hertzian wave current will tend to arrest the strong polarization (the production of fine gas bubbles) set up about the fine platinum wire, which is usually made the anode in the battery circuit. Further, the electrolytic detector has been found by Professor G. W. Pierce to act as a rectifier and that the inherent action is also based on polarization capacity at the electrodes as first described by Pupin in 1899. Dr. L. W. Austin and others have found that the fine platinum wire may be *positive or negative* for feeble oscillations with equal results. The acid solution is contained in a glass, carbon or zinc cup, and this acts as the cathode in the battery circuit. This detector possesses the function of acting as its own battery when a carbon or zinc cup is used, as this forms a miniature cell—carbon (or zinc) acid, platinum. This inherent battery action was intensified considerably by using a special amalgam in the acid solution in a detector of this class developed by H. Gernsback several years ago. The self-excited electrolytic detector has never been found (Pierce) to be as satisfactory as the externally excited one for feeble signals.

The operation of the sealed-point type ("Radioson") is the same as in the bare-point electrolytic type of detector and a battery of two

dry cells is used with it, together with a pair of high resistance telephone receivers and having the battery potential preferably regulated by means of a high resistance potentiometer.

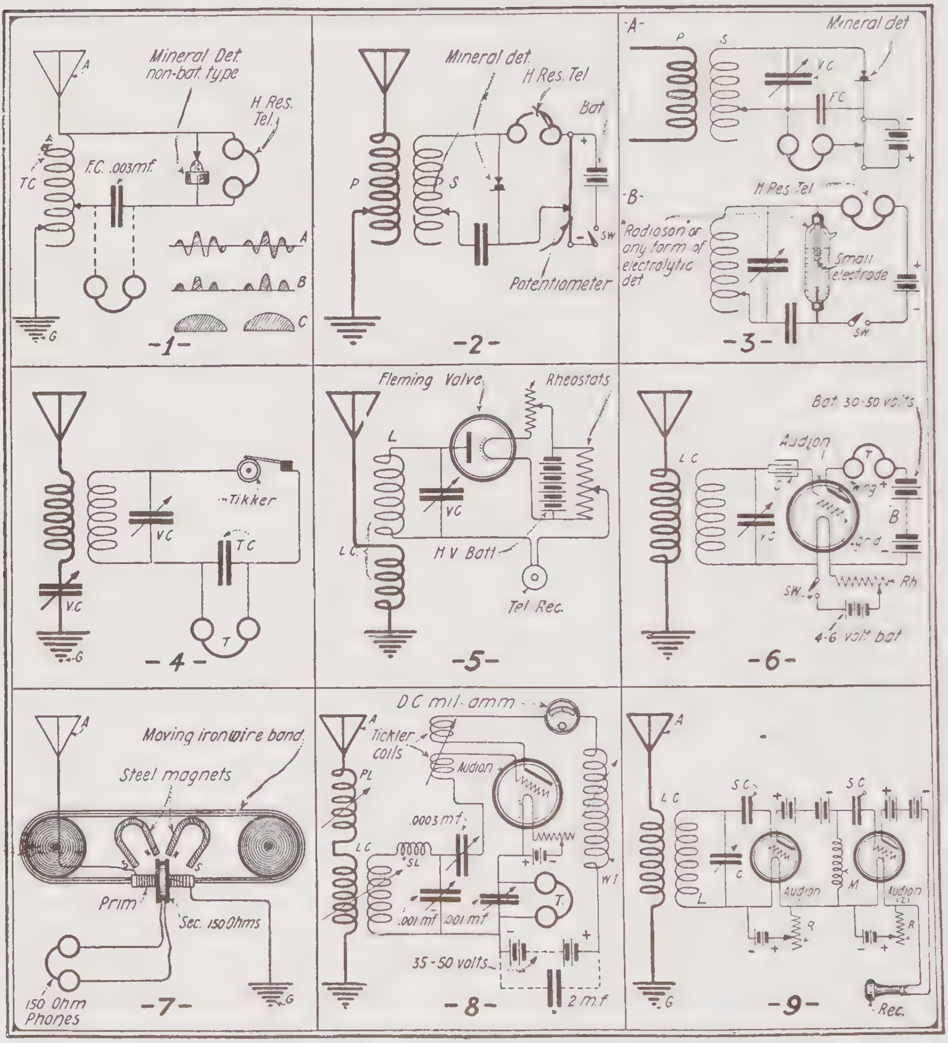
The advantage of this type of electrolytic detector is that the acid is sealed in, consequently does not spill or evaporate.

The *tikker* is used a great deal in translating undamped signals. It was devised by Poulsen and employs a small vibrator or rotary contact interrupter as shown at Fig. 4. No detector of the ordinary kind is used. The condenser connected across the 'phones should have about .02 m.f. capacity. It can be of the paper and tin-foil type.

The *Fleming Valve Detector* of Hertzian oscillations (Fig. 5) is based upon the principle that if we have a hot or incandescent electrode, and also a cold electrode, both mounted within an evacuated glass chamber, a rectifying action will be created, *i.e.*, that negative electrical charges, such as those from a battery of 30 to 40 volts or even less, can pass from the hot filament to the cold electrode, but not vice versa. In the Fleming Valve the cold electrode takes the form of a metal cylinder surrounding the incandescent filament. This arrangement acts as an electrical valve for oscillating or alternating currents of any frequency. The space between the cold cylinder and the hot filament is therefore said to possess unilateral conductivity. The Fleming Valve possesses a fairly high sensitivity; it is used with a pair of high resistance head 'phones, a suitable battery and auxiliary regulating apparatus. The wireless receiving phenomenon occurring will be evident from the foregoing and is, in a sense, of a rectifying nature similar to that possessed by the mineral detectors.

Since the Fleming valve detector has a very high resistance, the condenser VC should be very small, the inductance L relatively large, and the telephone receivers wound to a very high resistance, say 4,000 to 5,000 ohms, recommends Dr. W. H. Eccles. A peculiar fact about this detector is that its action is interfered with if the glass of the bulb becomes statically charged; hence the bulb is surrounded by a copper gauze screen which is earthed by connecting it to the battery supplying the lamp filament.

The *de Forest Audion Detector* (Fig. 6) employs three distinct electrodes as shown, viz., a filament—a grid—and a wing or plate. The grid, composed of a wire member as indicated, is placed between the filament and wing. The oscillations when they pass through



The leading detectors used in receiving radio signals are here illustrated, including the crystal, tikker, Fleming valve, and the audion.

the Audion detector are subjected to a similar action to that occurring in the Fleming Valve; that is, they are rectified, but in so doing they are found to also effect a relay action with respect to a high voltage battery of 40 to 50 volts potential, connected to a pair of high resistance telephone receivers in the *wing* circuit. Thus, with the Audion it is seen that, owing to the suggested relay action inherent in its operation, it is quite possible and practical to have such an action occurring of considerable magnitude; that is, the ratio between the amount of energy passing into the Audion from the antenna circuit, and the amount of energy controlled by the relay or *trigger* action in the high voltage 'phone circuit may be quite large.

There was, for a number of years, a great controversy on between the de Forest and the Marconi experts as to the validity of the Audion patents. This matter was discussed in the November, 1916, and also in the December, 1916, issues of the *Electrical Experimenter*, and those interested had best read both of these excellent articles as well as an exhaustive article explaining the electronic action of the Audion which appeared in the August, 1916, issue of the *Electrical Experimenter.*

The Marconi *magnetic detector* is a battery-less type much used on shipboard. It is illustrated at Fig. 7. The detector illustrated is the well-known Rutherford-Marconi *Magnetic Detector.* This instrument operates on a very unique principle, viz., that of the reduction in any hysteresis effect occurring in an iron core, when this core is subjected to the effect of a Hertzian wave current passing through the receiving circuit, according to the researches of C. Maurain. The complete detector is so arranged that a band of fine insulated iron wires constantly revolves about two rotary drums, driven by a spring or electric motor, and a pronounced hysteresis or magnetic frictional effect is produced in that section of the traveling iron wire band directly under the poles of a set of steel magnets mounted as shown. At this point there is also placed a small transformer containing a primary and secondary coil. Through the primary coil is passed the aerial current induced by the incoming electro-magnetic wave while to the secondary coil is connected a pair of low resistance telephone receivers.

It is evident, from the foregoing explanation, that at every in-

coming signal there will be a sound heard in the 'phones as the Hertzian wave currents flowing around the primary coil cause partial cessations or reductions in the hysteresis effect produced in the moving iron wire band.

One of the most important circuits used with the Audion detector is that using one bulb for producing an oscillating condition. This is shown in diagram Fig. 8. The circuit as here shown has been successfully used for several years by experimenters and others without the tickler coils, these being a new wrinkle, which tend to stabilize the oscillating conditions, once they are set up by tuning the various inductances and capacities. The condenser capacities are given. It is suitable for intercepting damped as well as undamped signals. The inductances are of the following dimensions:—primary of loose coupler is 10 by 5 inches, wound with No. 22 S.S. wire; the secondary is 10 by 4¼ inches, wound with No. 28 S.S. wire; the secondary loading coil SL measures 22 by 3½ inches with one layer of No. 30 S.S. wire, while the wing inductance WI is the same size with a winding of one layer of No. 30 S.S. magnet wire.

Beat reception with Audion amplifier connections has been accomplished with great success by Prof. A. Hoyt Taylor in the radio laboratory at the University of North Dakota. In his circuit, which has proved sensitive enough to pick up the German stations 4,300 miles away, and shown diagramatically at Fig. 9, use is made of two Audions, Nos. 1 and 2, both of which are chosen so as to be capable of generating oscillations. The 1 to 1 auto-transformer M (9,000 ohms) may be made from a spark coil secondary or a couple of them, through which a soft iron wire core is passed, and the whole sealed up in a tight cabinet filled with molten paraffin wax or sealing compound. This inductance M, allows current from the 35-volt battery to pass but stops high frequency or pulsatory current.

The stopping condensers SC, should be small, the second one being of about 0.5 billifarad (one billifarad=1 millimicrofarad or 10^{-9} farad). The variable capacity C should not be above 4 billifarads, thus permitting L to be large. For very long waves an aerial with a length of 800 ft., was used; its average height was 75 ft., and its capacity 0.013 m.f. The circuit LC is slightly mistuned from the signals and the Audion filament heated somewhat above normal, when working this circuit. The *beat* note is thus greatly amplified when it

reaches the high resistance telephone T. Prof. Taylor has done excellent work with this arrangement, hearing the German stations at Nauen (10,000 meters wave length), Eilvese (7,800 meters w. l.) and both the arc and spark signals sent out from the station at Honolulu, T. H.

CHAPTER IX.

Telephone Receivers.

THE telephone receiver as applied to radio-telegraphy and telephony is one of the most sensitive electrical detecting instruments ever devised. However, this does not mean that the *radio receiver*, as it is usually termed in wireless parlance, is the most efficient detector of weak electric currents. Quite the contrary, for it has been ascertained that such a receiver has an over-all efficiency of only *five per cent!** It was found by H. Abraham that less than *one one-thousandth* of the energy in the received current is transformed and transmitted to the air in the form of sound waves. Siemens conducted investigations which proved that the force of the air vibrations operating on a transmitter or microphone is *ten thousand* times greater than that of the vibrations reproduced by the receiver. Thus we see that the radio and electrical investigators of today have an excellent opportunity to devise and perfect a translating device of this nature that will show a higher efficiency than five per cent. Doubtless this ratio between input and output will eventually be raised to 50 or 75 per cent by some new principle of engineering design.

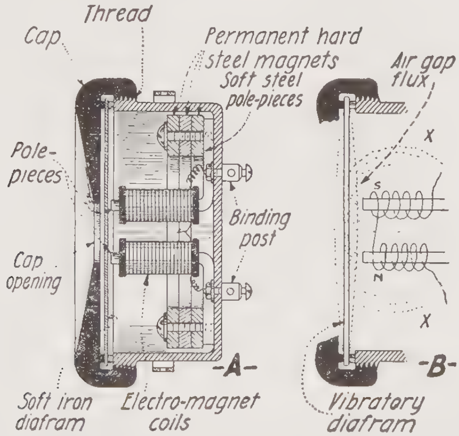
With all the losses in the telephone or radio receiver, however, it is interesting to note the infinitesimally small amount of energy required to give good clear signals or sounds; in fact, its sensitivity is almost incredible. Preece's investigations indicated that sound could be heard from a receiver when actuated by a current as small as .000,000,000,000,6 ampere. Tests by Kennelly indicated a minimum current of .000,000,044 ampere. For good radio communication the received current should be equal to 40 micro-amperes, through 25 ohms total antenna circuit resistance; this is equivalent to 40×10^{-9} watt = 4/40 erg per second. For audible signals the received antenna current should be about 10 microamperes through 25 ohms total aerial circuit resistance; this is equal to 2.5×10^{-9} watts or 1/40 erg per second.

Referring to Fig. 1, A-B, there is shown a sectional view of a typical watch-case radio receiver. In general this receiver follows the same design as that of the standard telephone receiver, with the difference that in this case the permanent steel magnets are concen-

* Shepardson, "Telephone Apparatus," 1917.

trated in a small ring so as to occupy less space. Two or more hardened steel magnet rings are used in the watch-case 'phone to which there are mechanically secured two soft steel pole-pieces on either of which a magnet coil is wound as indicated. The metal (or molded insulation) shell of the receiver carries a threaded cap with an opening at its center, through which the sound waves produced by the vibrations of the soft iron diaphragm pass to the ear chamber.

Practically all radio receivers follow this design, although there are several types that have been tried which deviate somewhat from the principle here involved.

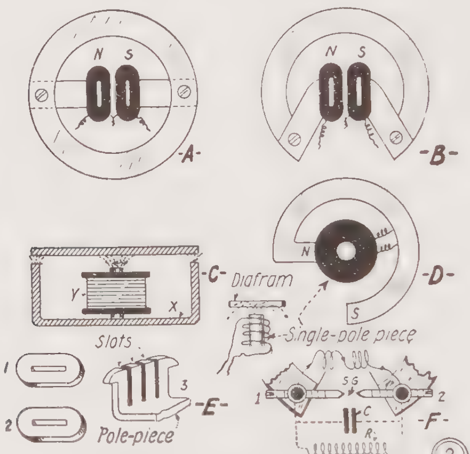


WATCH-CASE TYPE RECEIVER (1)

The receiver here shown is similar to the standard watch-case telephone receiver, with the exception that the magnet coils are wound to have a total or joint resistance of but 75 ohms for ordinary telephone work, whereas for translating radio signals, and owing to the very minute current available to act on the receiver, the two coils are usually wound to have a joint resistance of from 1,000 ohms to 3,000 ohms or more. The standard receiver for radio work has 1,000 ohms resistance, or two thousand ohms for a set of two receivers connected in series. The magnet coils should, of course, always be wound with a pure insulated copper wire, and the size of wire used depends upon

the resistance desired, varying from No. 36 B. & S. gage for a 75 ohm 'phone to No. 42 or smaller for a 1,000 ohm or higher resistance 'phone.

The permanent steel magnet in the receiver sets up or maintains a constant magnetic force acting on the iron diaphragm, as shown in Fig. 1-B; thus when the receiver cap is screwed down properly, the diaphragm will be held rigidly at a slight distance from the pole-



WATCH-CASE 'PHONE DETAILS

pieces, and will be pulled slightly toward them under normal conditions. The flux from the permanent magnet passes up one pole-piece across the air gap to diaphragm, through the diaphragm to the second air gap, through the second pole-piece and thence completes the magnetic circuit. If the cap is not screwed down sufficiently tight, or if the magnets are not properly adjusted, the permanent magnet flux may be sufficient to pull down the diaphragm against the pole-pieces in which event the receiver has to be overhauled, or the trouble may be overcome by tightening up the cap, or also in some cases it becomes necessary to place one or more paper rings under the diaphragm where it rests on the shell.

The action of the telephone or radio receiver is the same in every case. The vibration of the diaphragm, so as to set up acoustic waves in the air, is caused by sending a current of constantly changing

strength around the coils wound on the soft iron pole-pieces. These currents in the case of the telephone are controlled by a *microphone* in a well-known manner, and each current fluctuation along the circuit follows acurately the fluctuations of the voice. These current fluctuations, which often occur at a rate of several hundred cycles per second, pass through the magnet coils in the receiver and cause constant changes in the magnetic flux acting on the diaphragm; the flux from the electro-magnet coils either strengthening or weakening the flux from the permanent magnet which acts normally on the diaphragm, keeping it under constant stress. Where great sensivity is desired, it is claimed that a permanent magnet thus used to "stress" the diaphragm causes it to respond more quickly and easily to weak currents. It is becoming standard practise in the telephone field to make more and more use of plain *unpolarized* receivers, which have been found to reproduce speech in a perfectly satisfactory manner.

Probably the most important part of the receiver is the *diaphragm.* This is usually made of a high grade soft annealed iron which is then coated with Japan to prevent rusting, and in the best types of radio receiver the diaphragm is *Sherardized* to prevent rusting. Gold plated diaphragms have also been used. The diaphragm of the receiver fulfills the all-important function of transforming the vibrations created in the magnetic field into corresponding vibrations of the air which constitute *sound.* The diaphragm operates first as a part of the magnetic system, incidentally as part of the electric system, and finally as a mechanical vibrating system. In each of these relations, faithful reproduction of the original sound or signal requires that the motion of the diaphragm shall correspond in respect to direction and relative amount, with that of the electromotive-force applied to the terminals of the electric circuit, this in turn being assumed to correspond faithfully to the vibrations of the original sound.

For radio receiver circuits where the current is usually of the order of a few millionths of an ampere, and the voltage but a few millionths of a volt, it has been found that several parts of the receiver need redesigning and will bear a number of changes in proportion that would not augur well for the same receiver if it were to be utilized on a standard telephone circuit, where plenty of current and voltage are available. Experience in radio receiver design has shown that the diaphragm should be slightly less than two inches in diameter and clamped firmly all around the edge, the diaphragm itself be-

ing between four and eight mils thick. The natural pitch or vibration frequency of the diaphragm will be higher as the diameter and the thickness decrease, and vice versa.† In most cases the pole-pieces should be so near to the diaphragm as almost to pull it against them, and for this reason the magnet pole-pieces should be adjustable, as it will be found in practise that temperature has considerable to do with the best operation of the receiver, the diaphragm expanding and contracting considerably under changes of temperature, which may easily range from fifty degrees below zero in northern climates up to one hundred and fifteen degrees Fahrenheit in the tropics.

The technical consideration of the action taking place in a radio or telephone receiver is best understood perhaps by analyzing the changes occurring in the magnetic circuit, which is of course the all-important factor involved in the transformation of electric currents into sound waves. The pull on the diaphragm is approximately proportional to ϕ^2, where ϕ is the magnetic flux passing from pole to pole through the metal of the diaphragm. A current in the windings makes the pull $(\phi + d\,\phi)^2$. The increased pull due to the current is proportional to $2\,\phi\,d\,\phi$, neglecting a relatively small quantity. Therefore, the greater the permanent flux, the greater the efficiency of a good instrument. The flux is increased by strengthening the magnets or by using thicker diaphragms, also by reducing the air gaps between the diaphragm and pole-pieces, but magnetic saturation of the diaphragm sets the limit to useful increase of strength of magnet, as readily becomes evident. If, with a certain thickness of diaphragm we unnecessarily increase the strength of the magnet in the receiver, the superfluous magnetic flux which cannot be crowded through the diaphragm will simply be wasted in magnetic leakage as shown at X in Fig. 1-B. With diaphragms of given diameter, a thicker one carries more lines, is stiffer and can, therefore, be brought nearer to the pole-pieces, but a limit to *thickness* is soon imposed by the increase of stiffness and inertia, and also by the decrease in the natural period of vibration, which should also be in the neighborhood of the periodicity of the current sent through the receiver. The factor $d\,\phi$, due to the current, is improved for a given current by increase of the number of turns of wire linked with the magnetic circuit; but when the applied E.M.F. is supposed given, the resistance of the windings

† W. H. Eccles, "Wireless Telegraphy and Telephony," 1916.

has to be considered, which implies that the spools should be of small section and as nearly circular as possible. The spools are usually placed at the extreme ends of the soft iron pole-pieces, from which it follows that the pole-pieces must be reduced in section as far as possible without unduly increasing the reluctance of the magnetic circuit. As the diaphragm of the actual receiver is a stretched elastic body but tends to vibrate most easily and perfectly at a frequency, dependent upon its construction and elastic properties, which is known as its *natural frequency*, hence it is found that if the input current to the receiver is kept constant in amplitude, but if its frequency is varied, then the greatest response or motion of the diaphragm occurs when the *impressed* frequency *is identical* to the *natural* frequency of the diaphragm.

A factor which has been given considerable attention of late in the study of both radio and telephone receivers is that known as the *motional impedance.* Those interested in this subject will do well to consult an excellent paper giving a complete study of the telephone receiver diaphragm by Messrs. Kennelly and Affel, *Proc. Amer. Acad. Arts & Sci., Nov.,* 1915. Motional impedance as applied to the telephone receiver concerns the current induced in the receiver windings by the *movement of the diaphragm.* In other words, whenever the diaphragm of the receiver moves or vibrates, it changes the reluctance of the magnetic circuit, and in consequence changes the flux through the windings, thus causing an E.M.F. to be induced in them. If this were not so, the regular telephone receiver of the type here shown would not transmit speech without a battery connected in circuit with it. When the receiver has current passed through it and the diaphragm vibrates in consequence, the induced E.M.F. flows in an opposite direction to the current entering the windings and is a *counter E.M.F.* Thus, in the case of any telephone or radio receiver the *total impedance* of the windings is composed of *two* impedances, the *first* being that of the receiver winding, and the *second,* that of the reaction of the moving diaphragm.‡

In any event the total pull on the diaphragm of a telephone receiver is made up of three terms—one representing the pull due to the permanent magnetism alone, one representing the pull due to the current alone, and a *product term* representing the pull due to the

‡ Mills. "Radio Communication," 1917.

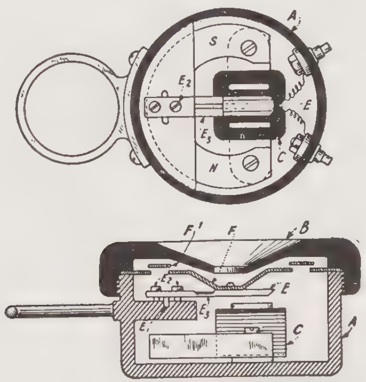
super-position of two magnetic fields, *viz.*, those due to the current and to the permanent magnet.

TYPES OF RECEIVERS

Several of the more distinct types of wireless receivers will now be discussed. Several unique features of construction are shown in Fig. 2. At A there is shown one style of permanent magnet used considerably in bipolar watch-case type receivers, and as will be observed, the pole-pieces are secured to either side of the circular steel magnet rings. It may also be said at this point that the two magnet coils are invariably connected in series and arranged to produce alternate *North* and *South* poles as indicated in the figure. At B there is shown a common arrangement of the watch-case 'phone and its steel magnet rings. Another form of watch-case receiver magnet is shown at C. This arrangement may comprise a permanent steel magnet, X, with an electro-magnet, Y, secured at the center. The diaphragm is then acted upon in this case at the center, and also at both sides. Some single-pole receivers utilize a permanent magnet punching similar to that illustrated at D. In this case the magnetic flux from the single-pole near the diaphragm has to return through the air, thus encountering considerable *reluctance* (magnetic resistance) of course, and these receivers are therefore not as efficient as the double-pole type, as the magnetic reluctance of air is several hundred times greater than it is for iron or steel. At E, Fig. 2, a typical pole-piece from a bipolar watch-case receiver is illustrated, where 1 and 2 are the fiber end-cheeks which are slipped over the pole-piece preparatory to winding the coil on it. The face of the pole-piece which is next to the diaphragm is swaged over as shown to hold the coil cheek in place. It is common practice to provide several narrow slots as shown in the drawing, these slots extending from the face of the pole-piece to the bottom of the coil section. Several of the best makes of wireless 'phones have these slotted pole-pieces, which tend to reduce the losses due to *Eddy currents,* which are produced in the face of the pole of any receiver whenever the diaphragm moves; representing a loss in efficiency and developing heat, etc. All the best grades of wireless 'phones are provided with some form of protective spark-gap or other device as shown at Fig. 2-F to prevent heavy static or other surges from burning out the windings in the receiver. A very small condenser is sometimes connected across the binding-post terminals of the receiver or else a

high resistance. If a spark-gap is used for the apparatus, it should be of the micrometer type provided with threaded electrode screws so that it can be adjusted very closely, the gap not being over .01 inch in length.

Fig. 3 illustrates a *vibrating reed radio receiver* patented by S. G. Brown in England. This receiver is of the watch-case type having

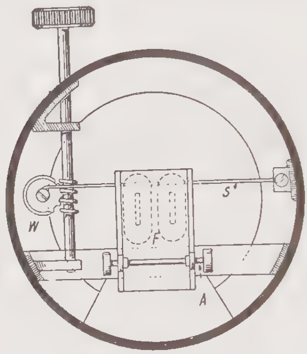


"BROWN" TUNED REED RECEIVER (3)

a shell, A, and an ear-piece or cap, B. The vibrating member comprises a steel reed, E, and a light, conical, aluminum diaphragm, F, attached at its center through the reed, E, and at a point a short distance from the center of the core axis. The conical diaphragm has its perifery close up against the casing. The central portion of the reed is cut away so as to make it more flexible, and also in this way it becomes possible to provide a tuned vibrating member, or a set of these members adapted to currents of various periodicities.

A unique type of *mono-telephone* is illustrated in Fig. 4. This receiver has a vibrating member arranged to be tuned to any definite frequency within its range. With such a 'phone it becomes possible, by simply turning a thumb-screw on the exterior of the shell, to adjust its armature to have a natural period of vibration corresponding to the frequency of the current applied to the windings. In the mono-telephone shown at Fig. 4, a light ferrotype diaphragm is secured between a tight wire and a fixed axle. The pitch or period of vibration

is adjusted by the thumb-screw and worm which control the tension of the wire. The electro-magnets and so forth are of the same type as used in all watch-case telephone receivers. Where the ordinary spark signals are to be interpreted or picked up, it has not been found particularly efficacious to use mono-telephone receivers, for the reason



THE MONO-TELEPHONE (4)

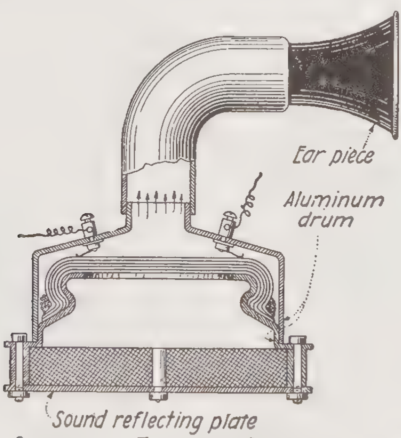
that the ordinary spark is very rich in overtones, and when a receiver is tuned to the spark rate, the energy of the fundamental is collected by the diaphragm, and that of the overtones thrown away.

The *condenser* or *electro-static receiver,* as it is more commonly known, is based upon the fact that a condenser can reproduce speech when connected into a suitable circuit. The electro-static or condenser receiver was first successfully applied by Prof. Dolbear. Elisha Gray, in 1875, found it possible to produce sounds by using the *dry fingers,* and he also at that time described a form of musical telegraph receiver based upon *electro-static attraction.*

Fig. 5 illustrates an improved form of *electro-static* telephone receiver. This receiver is provided with a sound-conducting tube and ear-piece, and at its base carries a sound-reflecting plate, as the drawing shows. In this particular design India rubber was found best for the condenser leaves, owing to its high insulating properties and low dielectric losses. An aluminum shell is provided as shown, which has an opening at the top and over which the alternating rubber and metal foil leaves are stretched. These rubber and foil leaves are firmly secured around the perifery to prevent any irregular vibration. Each

rubber leaf is about .4 m.m. thick. The sound-reflecting plate at the base of the receiver serves to reflect any sounds emanating from the inner surface of the condenser. The plates for the condenser are composed of aluminum leaf about .001 m.m. thick, these aluminum leaves being secured to the rubber leaves by a special process. When this form of receiver was tried with two hundred and forty volts, it was found that the volume was equal to that of an electro-magnetic *loud-speaking receiver* and the volume increased substantially with three hundred and four hundred volts, respectively. One of these condenser telephone receivers made and tested by Messrs. Ort & Rieger had a capacity of .088 m.f.

Several investigators have endeavored to produce a more efficient and perfect type of telephone receiver involving the heating and cooling of a fine electrical conductor. This principle is utilized in the *thermal telephone* shown at Fig. 6. This is probably the simplest form of telephone receiver ever designed, and of recent years

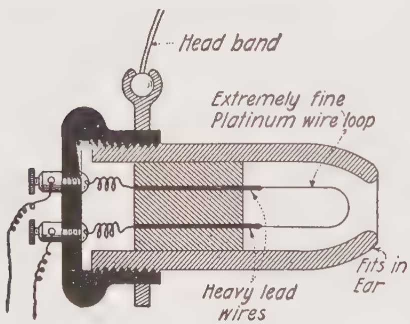


CONDENSER TELEPHONE RECEIVER ⑤

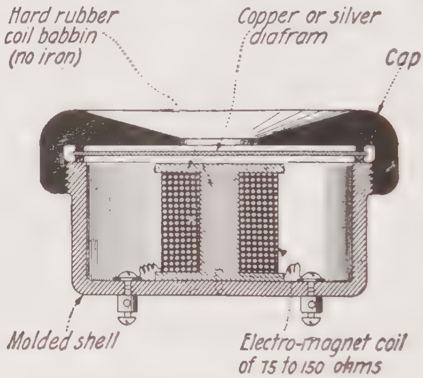
has been quite successfully developed in Europe, notably by Mr. DeLange. The receiver consists merely of a small tube provided with an opening, the tube being small enough to fit in the outer ear. The active member comprises a short loop of stripped Wollaston wire secured to two heavy lead wires in the manner indicated. In practice the tube containing the fine Wallaston wire is inserted in the aural passage: any sudden heating of this fine wire by a small current

creates an air pulse or sound wave vibration which in turn effects the ear drum. It has been found advantageous in some cases to have a small current passing permanently through the loop.

The *electro-dynamic receiver* is illustrated in Fig. 7. This is also known as a *dynamometer* telephone and was designed by Prof.



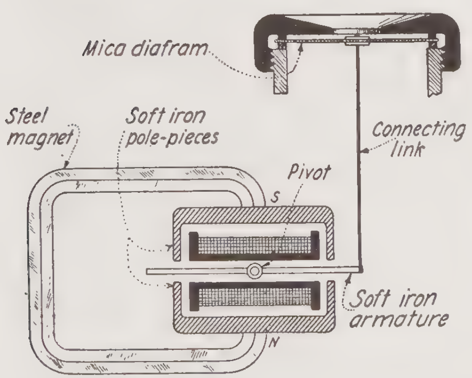
THERMAL TELEPHONE (6)



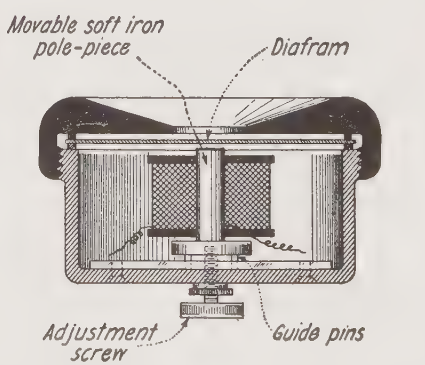
THE "PIERCE" DYNAMOMETER TELEPHONE (7)

G. W. Pierce for use with his type of wave-meter. This receiver is not as sensitive as the regular type, but for certain purposes it possesses many advantages, one of them being that it can be connected directly in series with the condenser and exploring inductance of a wave-meter (provided it is calibrated in connection with the wave-meter, thus allowing for the inductance of the winding in the receiver) as in the Pierce wave meter, in which case it will indicate the resonance point by giving a maximum strength of signal, the same as when a detector and a pair of 'phones are used. The construction of the dynamometer telephone is very simple, comprising as it does, a hard rubber or other insulating bobbin on which the magnet coil is wound, having a resistance of from seventy-five to one hundred and fifty ohms, and in front of this there is placed a light copper or silver diaphragm. No iron is used in the receiver, and its action is based upon the fact that attraction is set up between the current in the coil and the induced current in the silver or copper diaphragm. As Shepardson points out, even the diaphragm may be omitted, the minute movements of a loosely wound coil of wire being sufficient to reproduce speech or signals.

The *Baldwin amplifying receiver* is one of the latest developments in wireless receiving instruments and possesses a remarkable sensitivity. Its sponsors state that this receiver will amplify the incoming signals as high as nine times. A number of tests were made at the Radio Laboratory of the College of the City of New York with very gratifying results, this particular receiver having showed very superior results. As shown in the illustration, it comprises a permanent steel magnet which is provided with soft iron pole-pieces of the shape indicated, and between which there is placed the electro-magnetic winding of high resistance, also a light, balanced, soft iron armature pivoted at the center. One end of this armature is connected by a brass wire or link to a mica or isinglass diaphragm of standard size. The receiver shell is of normal size, although to those not familiar with this particular instrument such might not seem the case off-hand. Whenever a fluctuating current passes through the telephone winding, the soft iron armature is caused to vibrate, and these vibrations are



THE "BALDWIN" TELEPHONE (8)

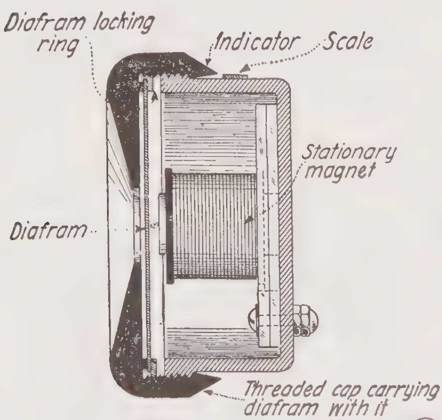


ADJUSTABLE POLE-PIECE 'PHONE (9)

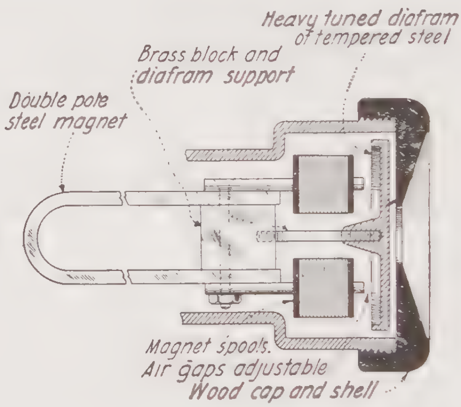
transferred to the diaphragm by the link already mentioned. As becomes evident, this receiver is unlike all other electro-magnetic receivers, in that the armature is under no magnetic strain until an incoming current passes through the winding. This is so, owing to the fact that the flux from the permanent magnet divides equally between both sides of the U-shaped, soft iron poles and continues through the magnets. Owing to this division of the magnetic flux, there is there-

fore no constant strain on the armature, as is the case in the common telephone receiver, as we learned in the fore-part of this article. The superior sensitivity of this receiver is due to the following: the magnetic circuit has a very low reluctance, and also the armature of the magnet is under no artificial strain until the current passes through the winding, thus yielding a greater deflection of the diaphragm, and again the armature is acted upon at both ends, and since the flux is produced differentially, the deflection for a given magnetizing current is correspondingly increased.

Fig. 9 shows a type of radio receiver developed several years ago, in which the pole-pieces are made adjustable by virtue of a small



"LEACH" ADJ. DIAFRAM 'PHONE (10)



THE "BERGER" MONO-TONE RECEIVER (11)

thumb-screw protruding through the back of the shell. As aforementioned, this type of 'phone permits the operator to correct the length of the air gap whenever the strength of the signal requires it, or also when temperature changes may cause the diaphragm to sag and touch the pole-pieces. For strong signals, the operator can thus increase the length of the air gap, and for weak signals he can advance the pole-pieces until they almost touch the diaphragm.

Another excellent type of adjustable air gap radio receiver is shown at Fig. 10. This is the "Leach" *adjustable diaphragm* receiver, the diaphragm being rigidly locked in the adjustable cap, so that whenever the cap is turned on the shell, the diaphragm will be caused

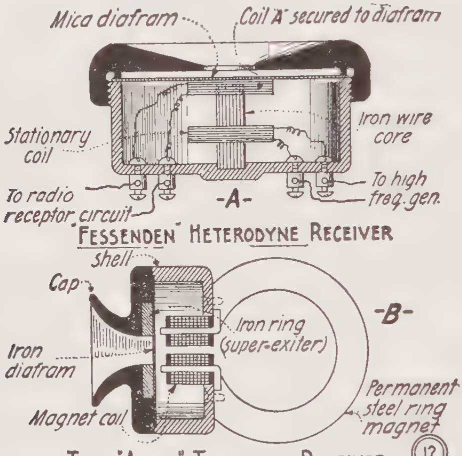
to recede from or advance toward the magnetic pole-pieces. The diaphragm is locked in the cap by means of a threaded ring. This 'phone has a graduated scale secured on the shell as shown, and an indicator is mounted or engraved on the edge of the movable cap. Thus when an operator has found a certain point on the scale which gives good results, he can reset the cap and diaphragm to that particular point whenever desired.

A novel form of *monotone* receiver is illustrated in section at Fig. 11, this particular type having been used with great success in submarine telegraphy and telephony. It was devised by a New York electrical engineer, Mr. Christian Berger, inventor of the submarine telegraph system now used on ocean-going vessels and submarines. This receiver is similar in design to other electro-magnetic types, and is provided with a permanent steel magnet. The novel feature of this receiver which puts it in the monotone class lies in the design of the special diaphragm. This diaphragm is comparatively heavy, even as thick as one-quarter of an inch in some cases, and as the reader will observe, it is not supported in the ordinary manner between the shell and cap of the receiver, but is mounted on its central axis upon a rigid stud secured to a brass block between the magnet poles. When a current of the proper periodicity or frequency is passed through the windings of this receiver, and providing the proper diaphragm, tuned to this exact frequency is utilized, then the fullest response possible with this form of instrument will be had; the tuned, tempered steel diaphragm of the bell type, vibrating at its own natural period with a maximum amplitude. Many unique modifications of this principle have been devised by Mr. Berger, and with this form of diaphragm the purest note imaginable is obtained.

At Fig. 12-A, there is illustrated the "Fessenden" heterodyne receiver which will translate and reproduce signals from an undamped wave radio station by the well-known principle of *beats*. Thus if an incoming signal has a frequency of fifty thousand cycles per second and this current is passed through a light magnet coil secured to the diaphragm of the receiver, while an auxiliary radio frequency current, having a periodicity of either forty-nine thousand or fifty-one thousand cycles per second, is passed through a stationary magnet coil mounted on an iron wire core as shown in the illustration, then the difference between these two frequencies, or, one thousand

cycles per second will be the *beat* frequency or the note heard in the 'phone.

A form of telephone receiver which seems to have considerable promise, and which has been used in Europe, is the *Ader* receiver, illustrated at Fig. 12-B. This receiver is of the watch-case type and



THE "ADER" TELEPHONE RECEIVER

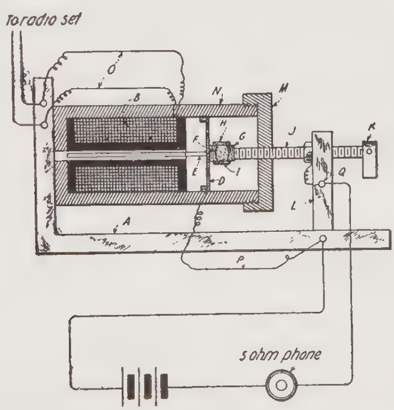
similar to a number of other receivers, being provided with a circular ring-shaped steel magnet on the poles of which are placed the two magnet coils. An iron diaphragm is used, and in front of this diaphragm there is placed an iron ring known as the *super-exciter*. The iron ring in front of the diaphragm tends to strengthen the action of the armature as it acts to render the field of the magnetic force more intense. Several telephone authorities have stated that they believe that the intensive effect of this type of receiver could be still further increased if the entire mouthpiece were made of soft iron. An interesting watch-case receiver used in Europe is the *Goloubitsky* type. This resembles the Ader receiver, but does not have the iron ring in front of the diaphragm, and is fitted with a second steel ring set at right-angles to the first one, and having two magnet coils placed on its poles. Thus, there are four electro-magnet coils acting on the diaphragm, all of the coils being joined in series. This form of receiver gives better results than those with two coils, but the extra weight does not compensate for the slight gain in efficiency obtained.

CHAPTER X.

Radio Amplifiers.

RADIO amplifiers of many kinds have been tried out in the relatively short time that Wireless Telegraphy has been with us. The more prominent types of current intensifying devices will be discussed here, reference being made to some of the novel or interesting ones. An amplifier is usually considered to be a device acting by electro-magnetic or other means so as to boost the strength of a received radio signal. Such apparatus is of the greatest importance in radio work, not only for the purpose of intensifying weak signals to audibility, but also for the control or modulation of heavy radio-telephone transmitter currents.

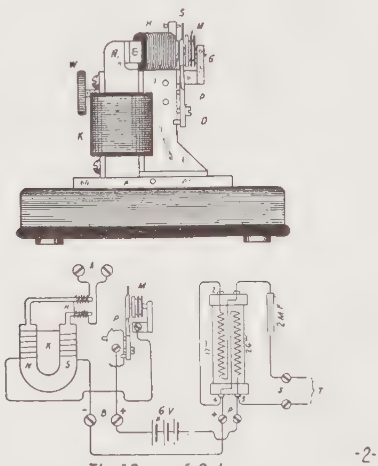
The electro-magnetic amplifier illustrated in Fig. 1, known as the "Multi-Audi-Phone," is claimed to boost incoming wireless messages *fifteen hundred times* their original audible strength of signals.



"Multi-Audi-Phone" Amplifier -1-

The amplifier consists of a special chemical placed between two electrodes, which arrangement changes the resistance by virtue of a diaphragm attracted to an electro-magnet. This will be more clearly understood by referring to a cross-section view of this instrument, Fig. 1. It consists of a permanent magnet A, supporting a metallic case N, having a threaded screw cap M. This case contains the amplification parts, comprising the electro-magnet B, which has a small iron core E connected to a very fine steel diaphragm D, carrying

a cup F upon its surface. Another cup G is placed on the opposite side and within it, the special chemical is placed at I. A tube H is provided so that the material is retained within the cups. The cup G is connected to a threaded rod J and lever K, supported by a rubber standard L on the steel magnet A. The diaphragm D is gold-plated in order that the chemical will not affect the steel. The electro-magnet B is connected by means of the wires O, while diaphragm D is joined to wire P. Rod J connects to terminal Q.



The "Brown" Relay

In order to regulate the pressure on the chemical mixture between the cup electrodes, adjustment is made by nut K.

The action of this amplifier is somewhat microphonic, and as the diaphragm is caused to vibrate by the incoming signals it varies the distance between the electrodes, consequently varying the resistance of the chemical and thus also the 'phone circuit. A 5-ohm 'phone is used in connection with this amplifier, so it is evident that a large current is used in this secondary circuit. A horn is usually fitted to the receiver, so that messages can be heard about the room without using a pair of head 'phones. If two or more of these units are used in cascade, signals can be boosted to such an audibility that one can hear the signals all over the largest room.

The *"Brown" Radio and Telephonic Relay.*—The electro-magnetic telephone and telegraph relay designed by Brown, of England,

is widely used for telephone current intensifying, and has been successfully employed for boosting radio signals.

Its make-up will be gleaned from Fig. 2, where N S is a permanent steel magnet frame surmounted by two magnetizing coils K, and two 4,400-ohm coils H (same size pole-pieces, etc., as used in a telephone receiver). A light spring or reed P carries a soft iron head to be attracted by the pole-pieces. Attached to the moving reed is a rod joined to a delicate microphone M, filled with polished carbon grains.

Referring to the diagram of connections in radio circuits we see that terminals A are joined in place of the regular telephones. The magnet coils K are energized by current from a battery of six volts through the primary (17 ohms) of an auto-transformer P. S. Across the transformer secondary (26 ohms) at 3, 1, is connected a 2 M.F. condenser in series with a pair of 120-ohm telephone receivers. Its action will now be clearly understood. The varying Hertzian currents react through coils H on the relay magnetic circuit balance, and cause its armature reed P and the microphone M to vary their positions. The microphone thus changes the resistance of the circuit, and these changes are transmitted through the transformer P S and condenser to the head telephones.

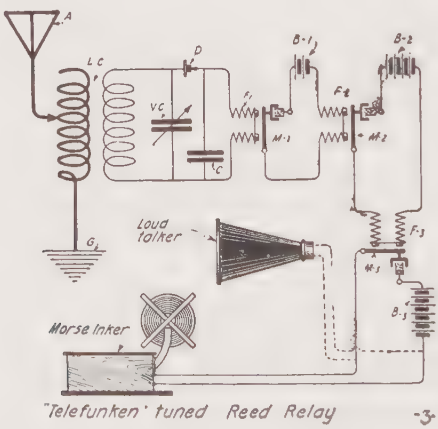
This style of Brown relay has an intensifying factor of about 20 times received strength of signal. Newer types can intensify 100 times and more, or several may be joined in cascade to give as high a ratio as required.

The "Telefunken" system utilizes a unique amplifier of the tuned reed microphone type, which is outlined at Fig. 3. A radio coupling circuit is joined to a "tuned" reed microphone relay F_1 M_1, and this reacts or controls the battery through a second "tuned" reed microphone M_2, etc., etc. Three microphones are commonly used. Two of these "tuned" amplifiers can receive two distinct messages on an aerial simultaneously without interference, if they and the incoming waves have a tune frequency differing by 20 per cent or over, it is claimed. Such microphonic apparatus is extremely delicate and must be very carefully adjusted and supported on elastic bands or otherwise supported in a shock-proof manner by employing felt, etc. The third microphone circuit may control a "loud talker" or Morse tape recorder as desired. These microphones are extremely well built to

permit of the most exact adjustment. The resistance of each microphone circuit, as well as the potential applied, is made finely adjustable.

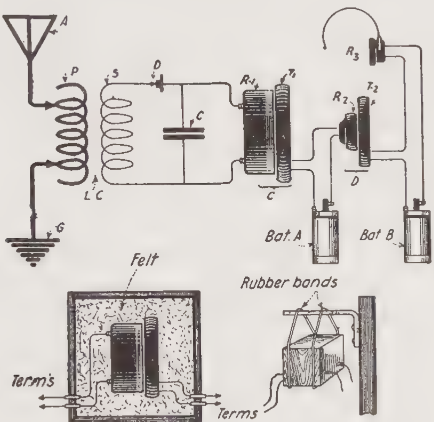
The "Detectiphone" Amplifier.—We come to an interesting application of the "Detectiphone" or dictograph, in the form of an amplifier for feeble or weak electric currents. At Fig. 4 there is outlined a system which has been tried out and which, when carefully and properly made, will yield good results.

Considering first the regular radio receiving instruments, with aerial A, ground G, loose coupler L C (or tuning coil), we see that the regular sensitive telephone receiver R 1, is mounted close up to a "Detectiphone" transmitter. An ordinary detector, finely adjusted, is connected at D, while C is the usual blocking condenser. The detector may be a crystal type or a Radioson, which requires no adjustment. This circuit, shown schematically at Fig. 4, is for a 2 stage amplifier, but a 3rd "Detectiphone" set gives better results of course. The bat-



teries A and B are the regular ones supplied with the instruments, or they may be ordinary $4\frac{1}{2}$-volt flash-light batteries. At T 1 is the first transmitter of a "Detectiphone" and its receiver at R 2; T 2 is the second transmitter and R 3 its regular receiver. The only high resistance wireless type receiver is that indicated at R 1. This should be a first class 'phone, and have at least 1,000 ohms resistance, and better yet 1,500 to 2,000 ohms; so as to be as sensitive to the rectified detector currents as possible. This arrangement of the apparatus

works on the principle that if a faint sound, such as a radiotelegraphic signal, be reproduced close to the ultra-sensitive transmitter of the "Detectiphone," then that faint signal will cause the diaphragm of the transmitter to vibrate, and thus cause variations in its resistance; which in turn are manifested in the receiver of the first "Detectiphone." These signals actuate the second microphone, and this in



"Detectiphone" Amplifier -4-

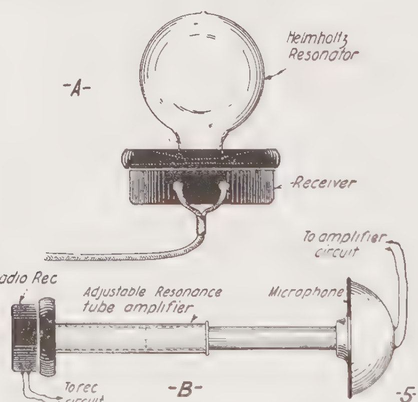
turn controls the third and final "Detectiphone" receiver at R 3. It is well to place a 10-ohm adjustable rheostat in series with each amplifying circuit, to enable the battery current to be regulated to a nicety. Not over 6 to 7 volts should be applied in any case to these "Detectiphone" circuits.

Several different arrangements and modifications of the apparatus may be made, and thus the experimenter and student is left a good chance for research work along this line. Step-up transformers can also be employed, as well as telephone induction coils, etc.

In making up such an amplifying set, care should be exercised to have the receivers and transmitters very close to each other, each unit mounted in a sound-proof, air-tight wooden box packed with felt, or other sound-deadening material. This is ensured by carefully removing the front threaded metal cover on the transmitter, and placing the wireless receiver diaphragm (with its cap removed, of course) up against the "Detectiphone" transmitter diaphragm. In fact the two may be glued together, so as to have a practically single period of

vibration, similar to the method utilized in building telephone relays. After doing this, and taking care not to spill the carbon granules out of the microphone, the receiver and transmitter should be bound together firmly with tape. The same directions hold, of course, for the second receiver and transmitter, stage D. At Fig. 4 there is shown a simple method of supporting the sound-proof wooden boxes, containing units C and D; by suspending them on ¼ inch rubber bands from an arm. This prevents extraneous vibrations from affecting the ultra-sensitive transmitters. This system has been applied commercially, and an amplification value of 15 times the initial received strength of signal has been obtained.

The "Helmholtz" acoustic resonator has been successfully used to boost the strength of signals as heard in the radio receiver, the glass bell of the resonator being placed close up to the receiver opening as shown in Fig. 5-A. It is particularly suited to use on regenerative valve sets, where a variable capacity is employed to vary the number of *beats*. The receiver used is preferably a standard 1,000 or 1,500 ohm type. The large opening of the resonator should fit over the opening in the telephone receiver cap. This type of pure acous-

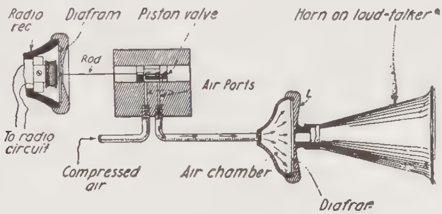


The "Helmholtz" Acoustic Resonance Amplifier

tic resonator responds only to a certain frequency for each size of bulb; therefore the resonator used should approximate the beat frequency used. Also the variable capacity in the Audion circuit should be varied until the beat frequency created permits the Helmholtz resonator to be in resonance with the receiver. On spark signals and

a crystal detector a resonator corresponding to the pitch of the incoming signals should be selected in each case.

Fig. 5-B illustrates an adjustable resonance amplifier which has been used with beneficial results, it is said. The resonance tube comprises two tight-fitting brass tubes, one sliding within the other, and the complete tube member joining a microphone and receiver, for ex-



Compressed air Amplifier -6-

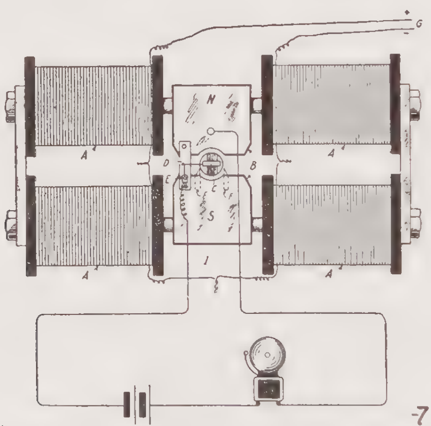
ample. The resonant frequency to which the tube will respond may be changed by sliding the inner tube in or out. The law of frequency for these tubes can be found in any good text-book on physics. Various sizes of tubes should be tried.

The "compressed air" amplifier. A new and extremely simple form of intensifier for telephonic, telegraphic and phonographic signals or sounds is the *Parsons compressed air* valve, shown in Fig. 6. A radio or telephone receiver, R, is connected by a rod, as seen, to an air piston or other form of valve. Whenever the receiver diaphragm moves, or signals are being received, it actuates or moves the air valve controlling the flow of compressed air to a loud talking diaphragm chamber, L, connected to a suitably large horn. This is only a general description of this most interesting amplifier, and further information can be gained from the phonograph companies using it, also by consulting the records of the Patent Office or back files of the *Electrical Experimenter* (October, 1915 issue, page 265).

The "Lowenstein" Electro-magnetic Amplifier.—This apparatus as designed by Fritz Lowenstein, of New York, will operate on any receiving detector and is recognized as the most sensitive detecting device for electric current of this particular type ever constructed for commercial use, as it will be deflected by a current of 1 micro-ampere (1 millionth of an ampere).

This super-sensitive relay is illustrated in Fig. 7. The moving

element C is wound with a coil of extremely fine wire and carries a contact D which makes connection with a small pool of mercury E, when the armature is deflected. The moving part is supported on two jewel bearings to eliminate friction and the connections to the moving coil consist of two very fine helical copper springs suspended at both ends. Two small discs, F, F, are provided to regulate the swing of the coil, which is mounted between two pole-pieces, BB, that are energized by the massive coils shown at A, A, A, A. The coils are so connected that the two pole-pieces will have different polarities, thus forming a N. and S. pole. The current for these magnets is obtained from a 110 volt direct current supply and is led in through the wires G.



"Lowenstein" Magnetic Relay - 1 micro-amp. sensitivity

The operation of this remarkably sensitive relay is as follows: The powerful electro-magnets are first excited and the moving coil is connected to the receiving outfit in place of the regular 'phones through terminals H, and a calling device, such as a bell, at the terminals I. When the coil C is excited by the feeble current produced by the detector, which, of course, is received by the other instruments from the radio transmitting station, it will turn, and its lever D will make contact with the pool of mercury E, thereby completing the circuit which causes the calling device to operate. The bell can be replaced with a tape register by which messages can be readily copied. This, of course, must be operated at a slow speed, as the moving coil

has an oscillation period of .1 of a second. The oscillating frequency period can be changed by varying the distance of the levers F. F, and the coil. The ivory or bone cup in which the mercury is kept can be moved either forward or backward by operating a small thumb screw located at the end of the container.

The complete relay is supported on a table that can be rotated to offset any detrimental effects of the earth's magnetic field. A suitable cover with a glass top is placed over the instrument to prevent any dust settling on the delicate moving parts. This device is capable of withstanding shocks and will work even when slightly tilted, for it has been tested on moving vessels and the results were entirely satisfactory.

Although the relay is adopted for radio work, it will be very useful in a laboratory where it is necessary to detect very minute or feeble currents. By mounting a sensitive microphone to make connection with the winding on the moving element this apparatus might then be used as a telephone relay, second only to the Audion in sensitivity.

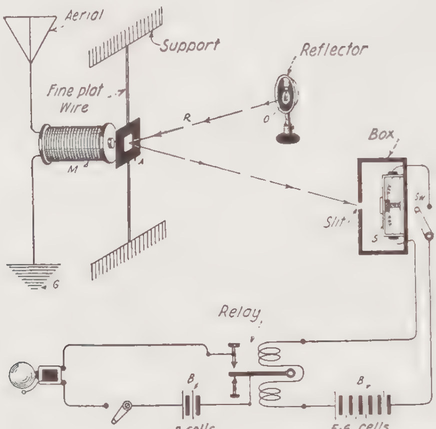
The "Selenium" Relay. Until recently the most sensitive relay was the Siemens polarized relay, which would close its contacts with about 0.00005 ampere.

The new selenium relay invented by Mr. G. Allstrom is said to respond to less than 0.00000000001 (one hundred billionth) ampere. See Fig. 8. This would make it even more sensitive than a telephone receiver, and experiments have shown that for wireless work it is well adapted for signaling and calling purposes, etc. The instrument has been used in connection with electrolytic detectors, which were always thought successful only in connection with telephone receivers. Loud, audible signals were never obtained so far with such detectors, but the Allstrom selenium relay makes it possible to use a sounder or tape register with any kind of detector, no matter how sensitive.

An extremely light piece of sheet iron, A, is hung between two platinum wires of the minute diameter of 0.0001 inch, etc. In the center of the iron sheet a small, very light mirror is cemented. An electro-magnet, M, which may have a resistance as high as 10,000 ohms, is placed immediately behind the iron foil, so that the magnet core almost touches the iron.

Some distance away a sensitive selenium cell, S, is stationed.

The cell itself is enclosed in a box, which at the front has a narrow slot. A source of light, O, is placed behind and directly over the selenium cell, and the room must, of course, be dark. By means of a parabolic mirror a beam of light, R, is thrown upon the small suspended mirror on A.



The Selenium Relay -8-

This beam is reflected towards S, but as long as the foil A, is motionless, the beam of light does not fall through the slot of S.

However, a minute current—such as a wireless wave—passing through the windings of M, will magnetize its core sufficiently to turn the very light mirror on A, and the ray can now fall through the slot of S, which reduces the resistance of the selenium cell. This is sufficient to operate relay R, which in turn will actuate the signal bell.

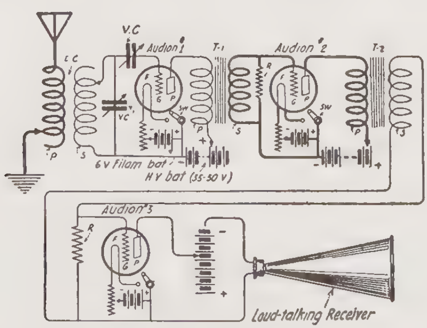
With suitable means the oscillations of A can be dampened so that it will return to its original position immediately after the current had passed through M.

In further detail it may be said that a magnet coil having 7,000 to 8,000 ohms resistance will be sufficient for the etheric wave relay coil M. Such a coil may have a very soft iron core about 5/8 inch in diameter and 5 inches long. Two fibre or hard rubber end discs are mounted at either end, whose diameter is roughly 2¼ by ¼ inch thick. The iron core is insulated with a couple of layers of heavy waxed paper. The coil can then receive about 11 ounces of No. 36

B. & S. gage enameled copper magnet wire. This gives approximately 7,284 ohms resistance for the magnet M, which adapts it nicely to the minute radio currents.

Further, the damping of the iron vane A, can be magnetic in character, so as to leave the vane free of an unbalanced weight. A permanent steel magnet, placed several inches from the iron vane, will have the desired effect in causing the moving member to come to rest quickly. Other methods are also applicable.

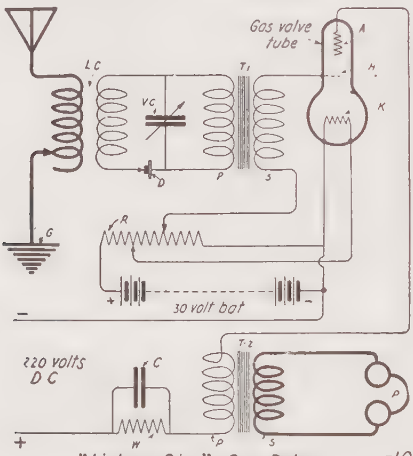
The "Audion" Amplifier. The vacuum valve or Audion amplifier is one of the best known and most widely used at this time. Fig. 9 shows the circuits for a cascade arrangement of three oscillation valves. The current fluctuations in the detector circuit are progressively impressed upon the grids of a second and third valve, and these valves, by virtue of their relaying action, result in a progressive amplification being attained. The loose coupler, LC, transfers the aerial circuit oscillations to the first oscillation valve, No. 1; the plate of this first valve is connected up with the usual high voltage battery and the primary, P, of a one-to-one iron wire core transformer. This transformer may be an auto-transformer, the winding having about 9,000 ohms resistance. A spark coil secondary is often used for the



The 2 (or more) "Audion" Amplifier -9-

purpose, placing a soft iron wire core through the center of the winding. The secondary winding is connected to the grid and filament of the second valve. Three to four valves are usually all that can well be employed in a simple type of cascade amplifier, as the oscillations in the third or fourth stage become so strong as to paralyze the valve. A high resistance (half a million to one and one-half

million ohms) is best connected across the grid and filament at R, to prevent excessive potentials accumulating on the grids of the second and third valves. The plate circuit of audion No. 3 is connected to a loud-speaking receiver, which may be fitted with a horn. Coupling transformer T_2, is of the same dimensions as transformer T_1. Bulbs Nos. 2 and 3 should be larger than bulb No. 1. According to Eccles, the three stage cascade amplifier, using ordinary sized bulbs, will yield an amplification of about 120 times; the third Audion will operate a sensitive magnetic type relay connected to a tape register.



"Lieben-Riez" Gas Relay -10-

The "Lieben-Reisz" Gas Relay. The newer gas or ionic stream relay, designed by Lieben and Reisz, the German investigators, is similar to the Audion, but possesses distinctive features of its own which render it particularly efficient as an amplifier for weak radio currents, which vary from 1 to 50 micro-amperes usually for fair signals. Their gas relay is shown diagrammatically in Fig. 10. Here a regular radio receiving circuit is represented with aerial A, ground G, coupling transformer L C, detector D of the mineral type, variable condenser V C, and a special transformer T_1. The primary of transformer T_1 takes the place of the telephone receivers usually employed. The secondary of the transformer acts on the valve tube shown at A H K.

The glass tube is exhausted of air and filled with attenuated vapor of mercury at a pressure of 0.001 mm. (20°C.), and this vapor rises from a small portion of mercury amalgam placed at the bottom of the tube. The cathode electrode at K is a platinum strip 1 mm. wide, 0.5 mm. thick and 1 meter long wound on a glass supporting stem, zigzag fashion. This strip is coated also with a thin layer of barium and calcium oxides. The anode electrode A consists of an aluminum wire spiral, while the auxiliary electrode H is made of a thin aluminum plate extending across the tube inside, between anode and cathode. It is punctured through with many holes about 3½ mm. in diameter.

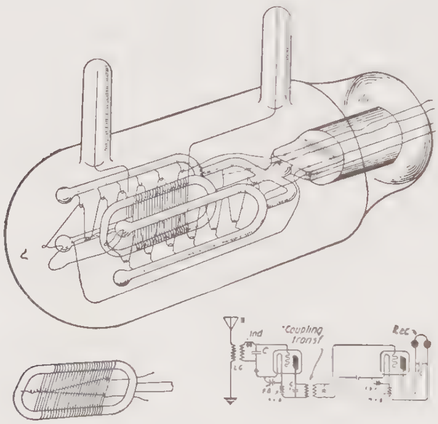
Also, in general, the cathode K is brought to a bright red heat by an electric current from the potentiometer R, attached to a 30-volt battery. Across the cathode and anode is impressed 220 volts D. C. from a dynamo, etc. The voltages must be kept quite steady. A high resistance W, shunted by a condenser C, is in series with the anode, as also the primary coil of a transformer (step-up) T_2. The secondary S connects with telephone receivers P.

It was discovered by Wehnelt that heated metallic oxids emit electrons; so in the Lieben-Reisz relay the heated cathode K gives off a stream of cathode rays or electrons (cathions), which pass through the holes in the grid H connected to the radio circuit through transformer T_1. The strength of the cathion discharge through H will depend on the potential of H. Hence it will be seen that varying grid H potentials are constantly produced by the received Hertzian wave signals acting through the circuit and transformer T_1. As the cathode stream is varied, so will the 220-volt current vary in proportion, and these variations will be heard as strong signals in 'phones P.

This valve tube acts therefore as a true relay, and it is said that one tube, as here shown, boosts the received currents to 33 times their original amplitude. Of course two or more tubes can be connected in cascade to give any amplification desired. This gas relay was supposed to be much superior to the Fleming valve and de Forest Audion in sensitivity, but as Eccles points out the de Forest patents cover similar devices of equal sensitivity, size for size. Reisz claims that with four of these relays connected in cascade it has been possible to attain a magnification of 20,000.

The "Pliotron" Amplifier. This is a form of vacuum valve devised by Irving Langmuir of the General Electric Company research

laboratory, and is claimed to differ from the Fleming valve and the Audion in that the instrument depends for its action on a pure electron discharge. In a pure electron discharge, as the temperature is raised, a point is always reached where the current becomes limited by the space charge between the electrodes. When this stage occurs but a small fraction of the electrons escaping from the cathode manage



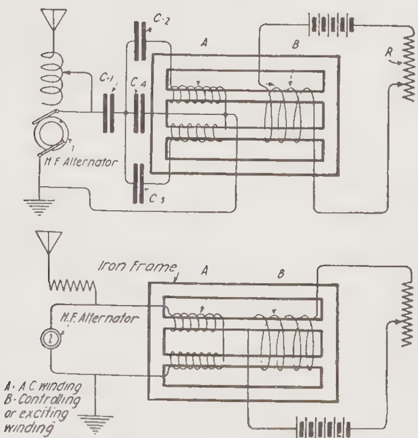
The "Pliotron" Vacuum tube Amplifier -11-

to reach the anode, whereas the majority of them are repelled by the electrons in the space and, therefore, return to and are absorbed by the cathode. Hence, if a negatively charged body is brought into the space between the anode and cathode, the number of electrons which then return to the cathode will increase, so that the current to the anode will decrease. If a positively charged body is brought near the cathode, either inside or outside the tube, it will largely neutralize the electrons in the space, and will, therefore, allow a larger current to flow from the cathode. By thus placing a variable potential electrode between the anode and cathode the current flowing between the anode and cathode may be controlled. This controlling member is usually in the form of a fine wire mesh or grid, as Fig. 11 shows.

The illustration, Fig. 11, shows the construction of the pliotron. A glass frame is used on which to wind the fine wire grid. In the figure the filament is mounted in the center of a glass rod frame, on which the fine grid wire is wound by means of a lathe; the grid often

consisting of tungsten wires as small as .01 mm., spaced as close as 100 turns to the centimeter. The operating characteristics of the "pliotron" depend upon the length of filament used, the distance between filament and grid, the spacing between grid wires, the diameter of the grid wires, the distance between grid and anode, and the size and shape of the anode. A circuit for using the "pliotron" as an amplifier is given in Fig. 11, in which case the high frequency currents received from the grid may be amplified one hundred to six hundred-fold. Here it is the radio and not the audio frequency that is amplified; thus the detector circuit can be tuned to the same frequency as the amplifier circuit with marked advantage.

The "Alexanderson" magnetic amplifier.—Referring to the accompanying diagrams, Fig. 12, we have two magnetic windings, A and B, related to one another magnetically and grouped on a laminated core structure in the peculiar fashion shown, there being a slot left in the central leg of the iron core. It is apparent that there can be no



"Alexanderson" Electro-Magnetic Amplifier -12-

direct transformation of energy from one winding to the other for the reason that each turn in the exciting winding B, includes both the positive and the negative branches of the flux produced by the alternating current winding A, which is connected in series (or parallel) with the high frequency alternator or other source of oscillating current. Hence there is no voltage induced in the winding

B. However, the current in either of the windings A or B influences the permeability of the common iron core, and therefore changes the inductance value of the other winding. Should the current flow in either winding be sufficient to saturate the iron core, it is therefore, rendered practically non-magnetic and the inductance of the second winding is reduced to the value it would have, if the coil included only air. When, however, a current flows in the other winding which gives a magneto-motive force equal and opposite to the first, the iron core is rendered magnetic again. As the two divisions of the A winding are wound relatively opposite to the B winding, the one branch will oppose the ampere turns of B on one-half cycle and the other branch during the successive one-half cycle.

The opposing ampere turns must be at least equal to the ampere turns in the winding B in order to have any flux variation in winding A.

The relations of currents in these windings is substantially the same as between the primary and secondary current in a transformer, although in this case one is an alternating and the other a direct current, or a current of a different frequency. It is thus obvious how the current flow in winding A can be regulated in proportion to the controlling current in winding B.

Short-circuiting condensers are connected to each of the radio frequency coils. A shunt condenser, C_4, across both coils and their short-circuiting condensers C_2 and C_3, increase the sensitiveness. Another condenser, C_1, inserted in series with the entire amplifier is employed to obtain linear proportionality of amplification and increased sensitiveness. The ratio of amplification is found to be proportional to the ratio of the frequency of the radio current to that of the controlling current. For telephone control the amplification ratio varies from 100 to 1 up to 350 to 1. It has been successfully used to control the out-put of a 75 kilowatt radio frequency alternator. With this amplifier it has been possible to effect a variation in the antenna energy from 5.8 to 42.7 kilowatts with a variation of control current of but 0.2 ampere. Think of effecting such a control—namely 37 kilowatts variation—by means of telephone transmitter.

This covers the important types of radio amplifiers. Radio investigators and experimenters generally will, however, undoubtedly find the following articles of interest which have appeared in the

Electrical Experimenter. If you cannot obtain a copy of the desired issues from the publishers you can see them at your local library in most cases.

Comprest air amplifier applied to phonograph. Oct., 1915, E. E. (Electrical Experimenter.)

Vibrating Reed Amplifier. By Samuel Cohen. Dec., 1915, E. E.

Amplifying telephone receivers, Baldwin patent. Jan., 1916, E. E.

Radium intensifies radio signals. Oct., 1916, E. E.

A new Magnetic Radio Relay—How to build one. It closes a local circuit for tape recorder or other apparatus. By Henri Mea. March, 1914, E. E., page 162. (Note:—The magnet coil dimensions given are in error; instead of one ounce each magnet coil contains 11 ounces of No. 36 B. & S. gage enameled copper magnet wire, giving a resistance of 7,650 ohms for the two spools in series.)

Selenium, Relay. See November, 1918, number of ELECTRICAL EXPERIMENTER, page 471

Audion Amplifier Action—Exhaustive discussion of electronic movements, etc. Complete article on this phase of the vacuum valve, August, 1916, E. E.

U. S. Navy Amplifone. See July, 1915, E. E.

CHAPTER XI.

How to Make and Use a Direct-Reading Wave Meter and Decremeter.

NO better use can be made of the Radio student's spare time than to construct and study the use of the *wave meter and decremeter.* The accompanying text and illustrations show how to build a home-made wave meter which will give very satisfactory service. The dimensions given for the various parts of the instruments are taken from an experimental one which was carefully calibrated for the writer.

We will first take up the construction of the wave meter and will afterward consider the calibration curves to be used with it, and also the determination of decrement.

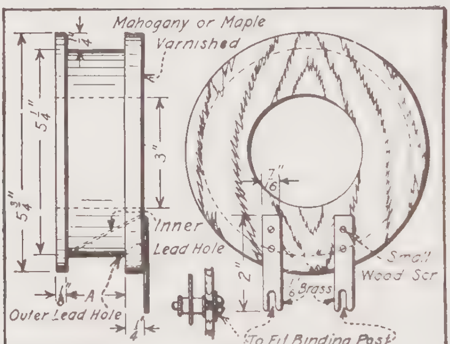


Fig. 1

Inductance Coil Data

Dimensions of 3 Inductance Coils			
Coil No. 1	12 Turns No. 20 B&S Enam Mag Wire	A = ½"	Ind cms = 36,000 cms
" " 2	24 " " " " "	A = 1"	" " " 26,000 "
" " 3	36 " " " " "	A = 1½"	" " " 259000 "

Perhaps the first part of the instrument that will come to hand as the student sets about the building of it, is the *inductance,* or rather the inductances. These coils are also referred to as the *exploring coils* or exploring inductances. They are used to pick up sufficient energy from a radio transmitter or receiving set, so as to cause oscillations to be set up in the wave meter circuit, which will be of sufficient strength to give a positive indication of resonance or non-resonance of the circuit, and thus to determine the exact period at which the current being measured is oscillating.

The illustration, Fig. 1, gives the details of construction for the three inductances used with this wave meter. The wooden forms on which the coils are wound are best turned on the lathe from some fine grained hard wood such as mahogany or maple. The physical dimensions of the forms are given in the drawing and the length A, of each of the three coils varies with the number of turns on each, the table in the figure providing these values for the different coils. The winding in each case consists of one layer of No. 20 B. & S. gage enameled magnet wire. These inductances have been accurately calibrated by comparison with a standard wave meter at the Radio Standardization Laboratory of the College of the City of New York, through the courtesy of Dr. Alfred N. Goldsmith, Director, and the specifications for building these coils must be rigidly adhered to. Where the accuracy of the instrument within a few per cent below or above the calibrated values is not imperative, No. 20 gage magnet wire, covered with a single winding of silk may be used; but due to the peculiar qualities of enameled magnet wire and the number of turns per inch of winding, etc., it will be seen that the specifications here given should be carefully followed to obtain the inductance values in centimeters here given. The three coils, numbers 1, 2 and 3, have inductances of 36,000, 126,000 and 259,000 centimeters respectively.

The manner of attaching the inductance coils to the wave meter cabinet is shown at Fig. 1, and consists of two lugs made of 1/16 inch brass and having slots at the lower ends of each. This enables the operator to slip the coils on and off the binding posts quickly. The inner and outer leads from the winding of the inductance should be carried through diagonally drilled holes in the wooden form, as is indicated by the dotted lines, and they should be soldered to the two brass lugs, which are screwed to the form by means of small flathead brass wood screws. The wooden form may be varnished or shellacked before winding, but the winding itself should not receive any coating of shellac or varnish, as this changes the distributed capacity of the coil. Do not use any iron in building these inductances.

The next item claiming our attention is the variable condenser, and we might say a great deal concerning this part of the apparatus, and then again we might just as well say very little. Experience dictates that this comes out about as follows: in the first place many radio experimenters would rather obtain on the open market a small

rotary type variable condenser having the proper capacity for use in this particular wave meter, and this should be .00086 microfarad. Of course any condenser having this capacity within a small fraction one way or the other may be used, but if the student wishes to have a good accurate wave meter, and intends to eventually have it calibrated or checked against a standard wave meter, then he will do well to select a sturdy and reliable make of rotary condenser. Some of the points to be watched in the design of such a condenser are that it should not have the rotary and fixed plates too closely spaced, or else it will frequently give trouble by short-circuiting; the rotary plates should be accurately locked on the rotary shaft either by having their hubs molded on the shaft or else they should be mounted on a square shaft so as not to turn, or again they can be keyed on the shaft. For the purpose of a wave meter there should also be practically no up and down movement or play in the vertical shaft supporting the rotary plates. For all practical purposes, the capacity of a rotary variable condenser (see Fig. 2), is determined by the usual capacity formula using a K value of 1, which is that for air.

Many radio amateurs and experimenters will undoubtedly wish to construct their own variable condenser having this required capacity, and the physical dimensions of such a variable condenser are given in Fig. 2. As will be seen, this particular design comprises

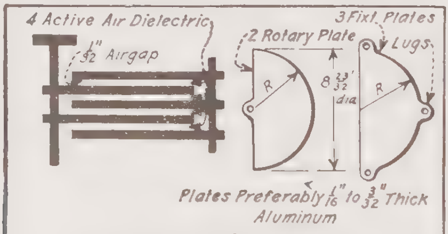


Fig. 2
Home-Made Variable Condenser

three stationary and two rotary aluminum or brass plates. These plates should preferably have a thickness of 1/16 to 3/32 inch so as to be perfectly flat and retain their shape, and thus maintain the accuracy of the condenser when once assembled. The four active air dielectric spaces between the plates should be exactly 1/32 inch. The diameter of the rotary plate, as Fig. 2 indicates, should be 8-23/32

inches, and by cutting the lugs on the stationary plates as well as on the rotary plate in the manner indicated, will permit of the accurate interleaving of the rotary and fixed plates so as to give the proper capacity.

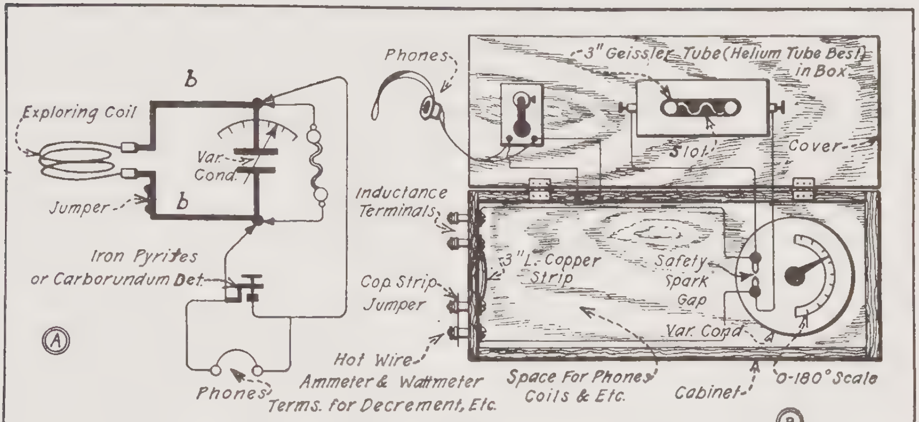


Fig. 3
Hook-Up of Wave Meter

Thus we see that the two principal parts of any wave meter are—an accurately calibrated precision variable condenser and an accurately calibrated inductance. In practically all cases this inductance and capacity of known values are connected together in parallel or shunt as shown at Fig. 3-A. Referring to Figs. 3-A and 3-B, the lead wires joining the inductance or exploring coil to the variable condenser are composed of two pieces of No. 16 flexible lamp cord, each 6 inches long. A 3-inch length of copper strip joins the two pairs of binding posts. Fig. 3 shows one set of binding posts being used for the inductance coil and the other set intended for the connection of a hot wire milliampere meter or thermo-couple and galvanometer. Ordinarily this latter pair of binding posts are fitted with a piece of copper strip about 1/16 inch thick forming a *jumper*.

It is well in all cases to fit a safety spark gap across the terminals of the variable condenser as shown at Fig. 3-B, as when the wave meter is used in close proximity to radio transmitting sets, there is very often a sufficiently heavy current induced in the wave meter

circuit to cause a puncture of the insulation of the inductance coil or a short-circuiting of the variable condenser, especially if the latter happens to have closely spaced plates.

For indicating the maximum resonance when measuring the wave length of a transmitting set, where the induced current in the wave meter is of course quite strong in any case, a very good indicator, as proven by practise and experience, is an ordinary 3-inch Geissler tube, or better yet a small *helium* gas tube. It is best when using either a Geissler or helium tube as an indicator of maximum resonance, to place the tube in a small box mounted on the lid of the wave meter, the box being blackened inside and provided with a slot in the front so that the degree of glow in the tube may be easily seen. It is also common practise to connect a hot wire milliampere meter in series with the inductance and condenser of the wave meter by removing the jumper on the series binding post terminals and connecting the meter to this; in this case the maximum resonance, and therefore the wave length at which the circuit under test is oscillating, is indicated by turning the condenser handle until the needle of the hot wire meter reaches a maximum reading. Some operators prefer to use the well-known detector and telephone receiver method of determining the maximum resonance point in the wave meter circuit as the diagrams at Fig. 3 show. The detector and wireless 'phones are connected (in series or in multiple) across the variable condenser for the purpose. This arrangement is extremely sensitive, and is the one invariably used in measuring the wave length of received signals. The Geissler tube or other apparatus is, of course disconnected from the wave meter circuit, if the detector and 'phone method is to be used. With respect to the detector used on the wave meter, it may be said that either carborundum or iron pyrites proves best, as either may be subjected to a very strong current without harm.

Figs. 4 and 5 show two more circuits used with the wave meter. Fig. 4 shows a detector and telephone receiver circuit, connected to the main oscillating circuit of the wave meter by a unilateral or one-wire connection. This method is highly recommended in many text books treating on the wave meter and its uses, and at the present time it is used on many of the best commercial wave meters. This connection of the detecting circuit possesses the advantage that it cannot have any dëtuning or offsetting effect on the oscillating circuit as is the case where it is placed in shunt to the capacity and inductance

composing this circuit, and it is very efficient for the purpose in hand, as with this connection the detector and 'phone receive just a sufficient amount of energy to operate them in the proper manner for giving a good indication. At this point, it is well to mention that no matter which form of detector is used in conjunction with the wave meter,

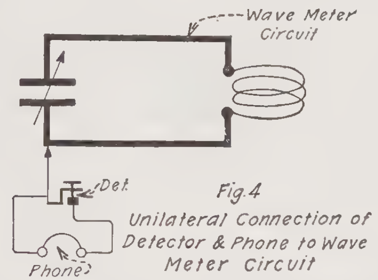


Fig. 4
Unilateral Connection of Detector & Phone to Wave Meter Circuit

that the wave meter itself must be kept at a sufficient distance from the exciting circuit, no matter what its form or make-up, so that there shall be just sufficient current picked up by the wave meter oscillating circuit to give a good clear indication in the detecting or indicating device. If the wave meter is held too close to the exciting circuit, then several wave lengths or harmonics of various wave lengths may be heard, and an incorrect reading obtained.

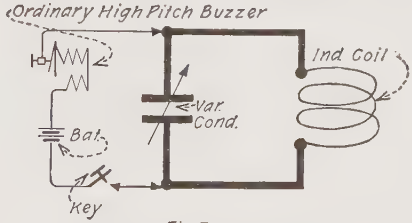
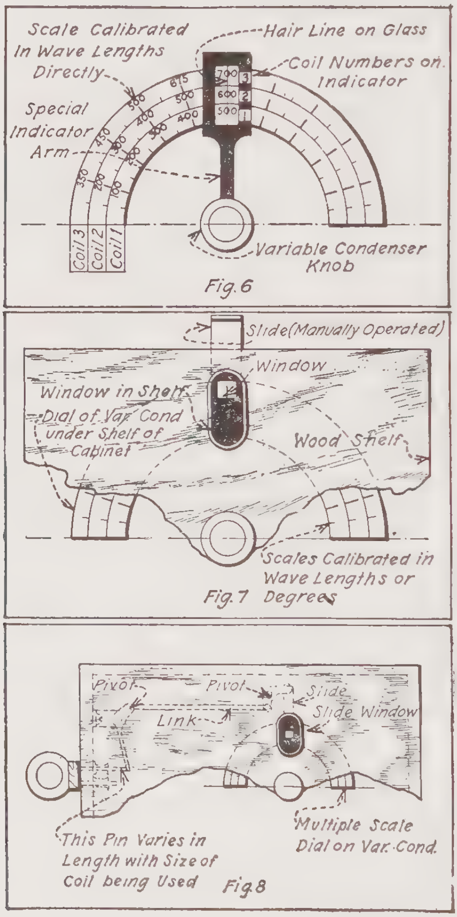


Fig. 5
Exciting the Wave Meter

For many purposes it is desirable and necessary to excite the wave meter so that it will radiate a wave length of known value, such as in various radio measurements, etc. Fig. 5 shows a standard method of exciting the wave meter. Here we have a high note or other form of buzzer connected with a few cells of dry battery, and

a key or switch. This circuit is shunted across the variable condenser of the wave meter as the diagram indicates. This arrangement will cause oscillations to be set up in the oscillatory circuit of the wave meter, and an auxiliary inductance can be placed near the wave meter



inductance so as to link the two inductively, and thus transfer the energy electro-magnetically from the wave meter circuit to the auxiliary circuit, and which energy shall have a wave length and frequency of known value.

At this juncture, the matter of arranging the wave meter cabinet, and especially the variable condenser and its scales, etc., should be considered. In this connection we may refer to Figs. 6, 7 and 8, wherein several important and simplified methods of arranging the variable condenser scales, especially direct reading scales, are given. Fig. 6 shows a method used by the writer for several years with good satisfaction. In this scheme the variable condenser scale is especially made up on heavy bristol board or celluloid, (or else hard rubber with the graduations scratched in with a scriber and then filled with Chinese white), and instead of having simply the angular spaces marked off in degrees, and then having to refer to a calibration chart in the usual way, the corresponding wave length values for the coil are read off from the calibration chart (see Fig. 9) and marked off on the scale as shown in Fig. 6. Then as the indicator attached to the variable condenser knob is moved over the scale, and by noting which inductance coil is in use at the moment, the corresponding wave length may be read off directly as soon as the maximum resonance point is indicated by the detecting circuit. The indicator, Fig. 6, comprises a piece of heavy sheet brass, soldered or otherwise secured to the shaft of the variable condenser, and the outer end of the arm is cut to the form shown, with the two side edges bent over to retain a piece of ordinary glass. With a glass cutter, a straight line is scratched across the center of the glass, and this may be darkened if necessary with a little black pigment. A piece of fine wire can also be drawn across the glass and soldered in place.

Fig. 7 illustrates a clever arrangement which also provides a direct-reading wave meter, and here the calibrated dial corresponding in its lay-out to that shown at Fig. 6, is secured to the variable condenser shaft *below* the shelf of the cabinet. A small oblong window is cut through the cabinet shelf as shown, and with a brass slide is placed underneath this shelf so as to be readily operated by hand, in such a way that the small window cut in the slide can be slid into any one of three positions, depending upon which scale and which inductance is being used at the moment. Fig. 8 shows an automatic arrangement, which is easily made by the radio student and whereby each of the three inductances is fitted with pin contacts, one of the pins in either case being made of a different length for each of the three coils. As each inductance is placed in the cabinet through the spring contacts shown, the longer lug will actuate a lever system con-

nected to the window slide shown at Fig. 7, and thus automatically move the slide to the proper position to read the corresponding wave lengths for that coil.

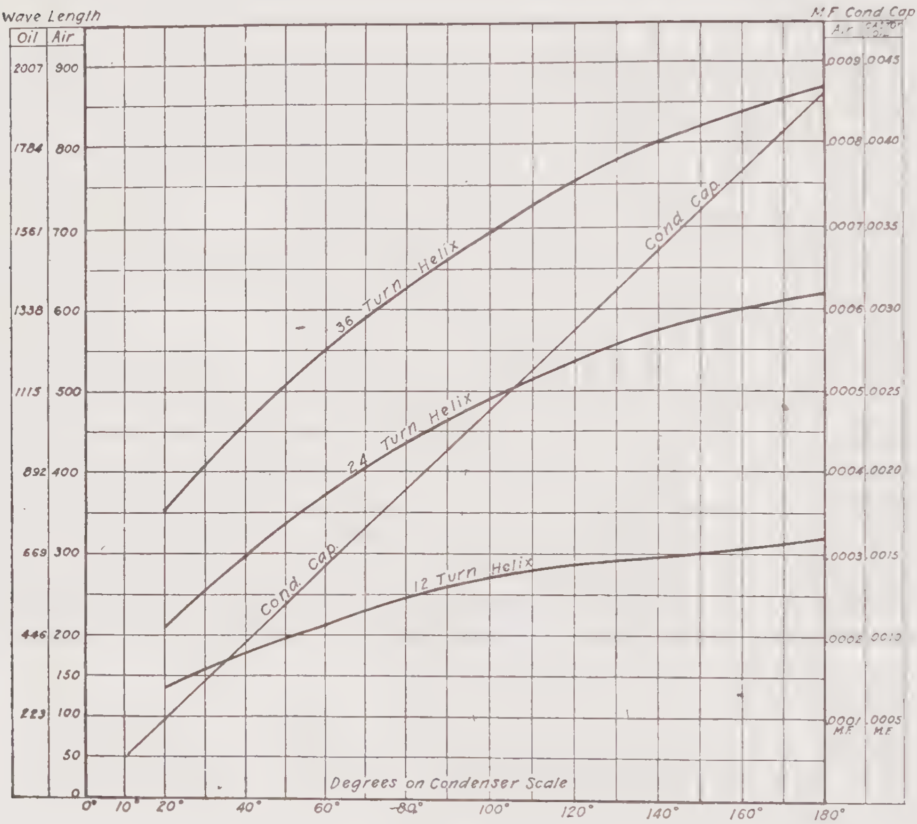


Fig. 9.

The calibration curves for the wave meter here described are given at Fig. 9. These values can be transposed to a special variable condenser scale if desired, of course. The variable condenser calibration curve is given as well as the wave length graph for each of the three inductances. As is well known, the capacity of a condenser may be increased by adding a liquid dielectric, such as *castor oil,* which has a coefficient K value of 5; or in other words, if the variable condenser is filled with castor oil, its capacity will be increased five times over that of air. The capacities for the condenser filled with castor oil

(as well as air dielectric) are given at Fig. 9 on the right. Also in this way the student will have a greatly increased wave length range on the wave meter for any given coil, when the condenser is filled with castor oil, as the second column of wave length figures on the left indicates. The manner of using the calibration graphs is as follows: Consider that a maximum resonance point is indicated by the detecting instrument connected to the wave meter circuit, when the condenser needle stands at 105 degrees, with the 24 turn inductance in use. Glancing upward from the 105 degrees marked at the base of the chart, and noting the point where this line intersects the curve for the 24 turn helix, we find that the equivalent wave length for air dielectric in the condenser is 500 meters, and for castor oil in the condenser 1115 meters.

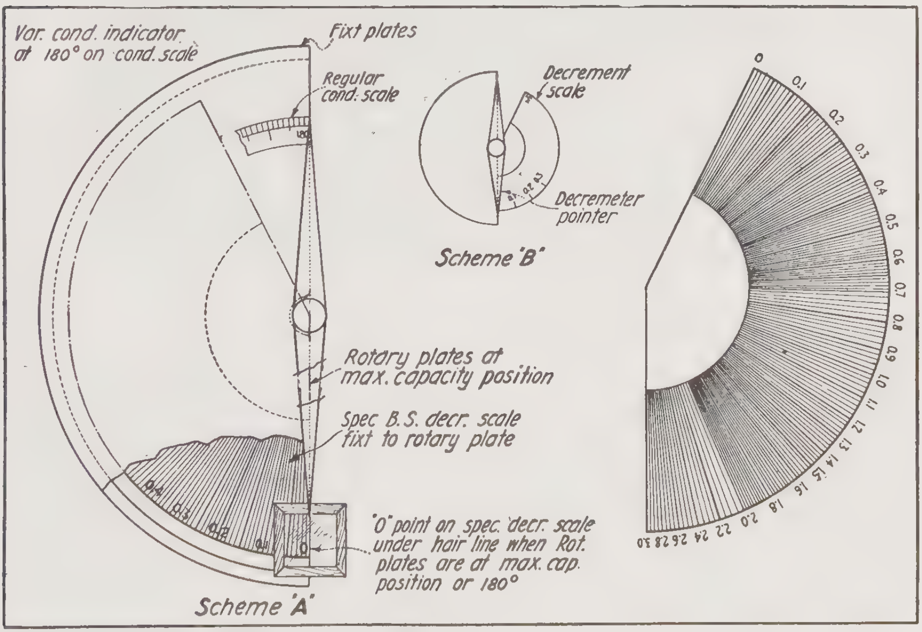


Fig. 10.

Direct-Reading Decremeter.—The chart shown at Fig. 10 is described in a recent book entitled "Radio Instruments and Measurements," Circular No. 74, issued by the United States Bureau of Standards, and a copy of which can be obtained from the Government

Printing Office, Washington, D. C., at small cost. This chart makes a *direct-reading decremeter* out of any wave meter. Fig. 10 shows how the chart may be attached to the upper rotary plate of the variable condenser; its zero graduation being set to coincide with an in-

Photograph of Author's Wave Meter Fitted with Calibrated Condenser and Inductance Coils of the Dimensions Given in the Present Article.

dicator mark or hair line through a window in the top of the condenser case, when the rotary plates are all the way within the fixed plates. Also it should be seen that the hair line in the window coincides with the straight edge of the semi-circular fixed plates. Full description of this arrangement is given in the work above referred to, as well as all the usual methods of measuring decrement.

Fig. 10-B shows an optional method of mounting the special direct reading decrement scale on the lid of the wave meter cabinet. In this case, the shaft of the rotary variable condenser is fitted with a double pointer as shown also at Fig. 10-A, but which in this case is superfluous.

As is well-known, the value of the decrement increases as the capacity of the circuit decreases. The zero graduation on the decre-

ment scale when the latter is placed on top of the wave meter cabinet, should correspond or line up with the diametrical edge of the stationary condenser plates as shown at Fig. 10-B.

Now, when the condenser shaft is turned and as the condenser scale divisions decrease in value, the decrement values will rise and vice-versa. It will also be seen on reflection, that the same result is obtained by mounting the paper decrement scale on the top rotary plate, as in Fig. 10-A, the values of the decrement increasing under the hairline of the window in the wave meter cabinet as the rotary plates are turned out of the fixed plates, and also as the capacity is decreasing.

When the logarithmic decrement of a certain wave is to be measured by this type of converted wave meter or decremeter, the value of the decrement is not indicated by a single reading. In order to utilize this decrement chart on the rotary condenser in practise, the following procedure must be adhered to:

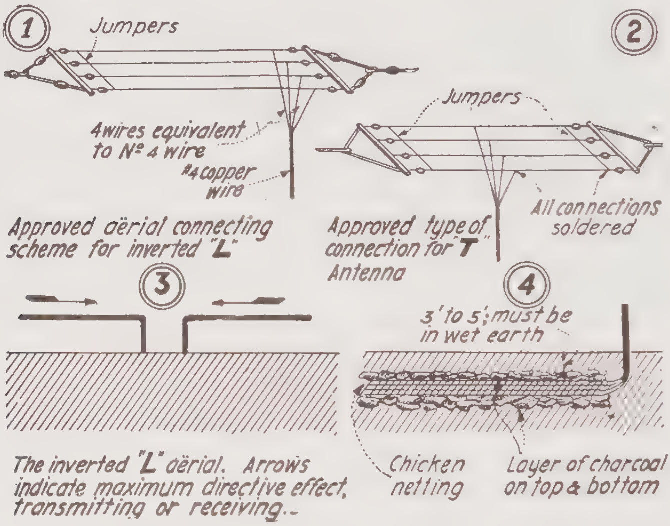
The wave meter circuit must contain or have connected in it, a radio-frequency current-square meter. Now observe the current-square at resonance, then read the decrement scale on a condenser setting on each side of resonance for which the current-square is one-half its value at resonance. The difference between the two readings on the decrement scale is the value of the decrement sought. It must be remembered, however, that the decrement thus obtained, includes the decrement of the wave meter itself, which latter must be known from the calibration of the instrument and then the value of this "instrument decrement" subtracted from the value found previously, which gives the true decrement of the wave being measured. This decrement scale may be used on any condenser with semi-circular plates as pointed out in the work above mentioned. This scale gives accurate results if the capacity scale is so set that its indications are proportionate to the capacity in the circuit. The scale permits accurate measurements of fairly large decrements but offers no precision in the measurement of very small decrements, particularly at the low-capacity end of the scale.

CHAPTER XII.

Radio Antenna Construction.

Types of Aerials.

THERE are various types of antenna adapted to the amateur and experimental requirements. Among the usual types of antenna with which Radio Amateurs are familiar are the "T" and inverted "L." The so-called umbrella aerial is quite familiar to some workers in experimental radio, but is seldom used except in more or less elaborate stations where experiments are carried on for *directive* effects. A typical form of inverted "L" aerial and the proper connections for the wires composing it, is shown at Fig. 1 in the accompanying diagram. Fig. 2 shows an approved form of



"T" aerial. The "T" form of aerial has a smaller amount of inductance than the inverted "L" type, its mean length being the length of the lead-in and rattails, plus one-half the length of the flat top. Hence, under certain conditions, as for instance, where two tall trees or other elevations may happen to be available, the whole may have to be exceptionally long for the requirements in question; then the inductance may be reduced by using a "T" connection, thus giving a lower operating range of wave lengths for the whole antenna. The

inverted "L" type aerial is fairly *directive* in its activity, and Fig. 3 shows the maximum directive effort both for transmitting and receiving. As Fig. 3 shows, where there are two inverted "L" antenna in use at two stations working with each other, such as in trans-Atlantic radio telegraphy, then the two inverted "L" aerials should point away from each other. In other words, maximum transmission or reception takes place *in a direction opposite to the free end* of this antenna, as the arrows indicate. Also, the longest distance station you wish to receive from should be in a direction opposite to that in which the free end of the aerial points, or in a direction pointing away from the knee.

There are two new forms of antenna, which will warrant considerable experimentation on the part of the Radio Amateur Fraternity, as they possess many very desirable features. They materially reduce the construction labor and expense, not to mention the danger in wind-storms from the destruction of masts, etc., and furthermore these new aerials can be used during thunder-storms, which has never been the case with the best of overhead antenna. The aerials of which we speak are the *surface* and *underground* antenna.

Not very much has been said in print concerning the *surface* antenna, which is formed of several insulated wires laid on the ground and then connected to the apparatus, which apparatus may or may not be connected to the usual ground. But very excellent work has been accomplished indeed with these aerials by Dr. Taylor, at the University of North Dakota. Messages have been received over distances of several thousand miles with aerials of this type.

The other form of ground aerial, namely the *underground and underwater antenna,* devised by Dr. James Harris Rogers, of Hyattsville, Md., possesses a great many meritorious and heretofore unobtainable features, such, for instance, as permitting the reception of radio messages right through heavy thunder-storms, when the static in regular elevated antenna was so severe that sparks eight to ten inches long would jump clear across the aerial switch.

In the present article we will deal more with the construction of the *elevated antenna,* as it will undoubtedly be used for a considerable time by Radio Amateurs and Experimenters, owing principally to the fact that it is rather difficult for amateurs to construct a sufficiently well-insulated Rogers underground or Taylor surface antenna, which will hold the charge of several thousand volts from a trans-

mitting set, without breaking down the insulation to earth and thus destroying its efficiency. We would refer the reader to the original article on the Rogers *underground antenna* by the author which appeared in the March, 1919, issue of the *Electrical Experimenter,* and for those who reside in cities or other congested districts and cannot run a long wire in a trench and bury it without being arrested by an ever present "blue--coat," the student so situated will find much consolation in a later article prepared by the author in collaboration with Dr. Rogers, entitled "The Rogers Underground Aerial for Amateúrs," which appeared in the June, 1919, issue of that journal, and wherein various forms of spiral antenna which can be used in the operating room or else buried in wells, brooks or down in the cellar, were described. Several other articles in this direction should be carefully studied by the student, one being "Loop Antenna and Direction Finders for Amateur Use," which appeared in the August, 1919, number of the *Radio Amateur News,* another article, "Concentrated or Loop Aerials," by Prof. Lloyd M. Knoll, A.M., appearing in the August, 1919, issue of the *Electrical Experimenter,* and "Underground Radio Made Possible for the Amateur," by E. T. Jones, in the December, 1919, *Radio Amateur News.*

Wave Length of Antenna.

Undoubtedly the first question that the Radio Experimenter will ask in relation to the antenna which he intends to build is: "What will the wave length of my antenna be?" In the first place, and although it might seem almost paradoxical to make such a statement, it may be said that radio experimental stations use antenna of all sizes. You may find that the owner of one station is interested, as a great many are, in receiving or trying to receive signals from the high-power European stations, such as Nauen, Germany; Lyons, France; Rome, Italy; or Carnarvon, Wales, England. Therefore, when such is the case, you will probably be surprised to see an aerial, either underground, surface, or elevated, ranging away from the station for a distance of possibly 1,000 to 4,000 feet! These high power stations are using wave lengths almost beyond the dreams of our most eminent radio experts of pre-war days. Wave lengths used by these stations in various parts of the world, including the United States, run up to 10,000, 12,000, 15,000 and 20,000 meters quite frequently.

Before going further, we should consider most probably the size

of antenna required in a Radio Amateur station, where a *transmitting set is to be used.* Amateur transmitting stations, whether they are licensed or not, must not have a transmitting wave length exceeding 200 meters. Unless an inefficient energy-wasting *series condenser* is to be used in the ground lead in the aerial oscillatory circuit, then, in order to radiate a wave length not exceeding 200 meters in length, the antenna to be employed can hardly exceed 80 feet in length for the flat-top, with an altitude of 50 to 60 feet, comprising a four-wire inverted "L" aerial, the wires being spaced about 2½ feet apart.

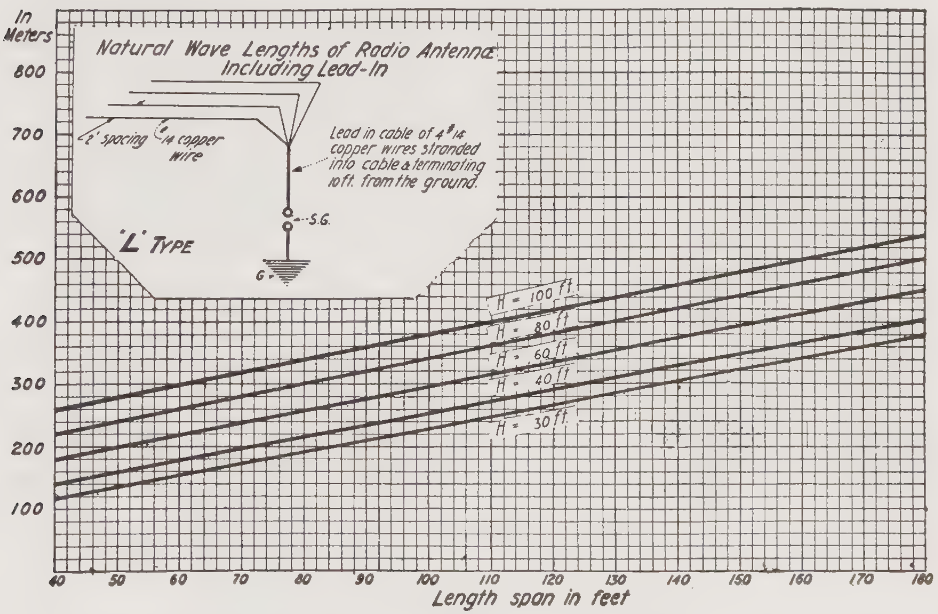
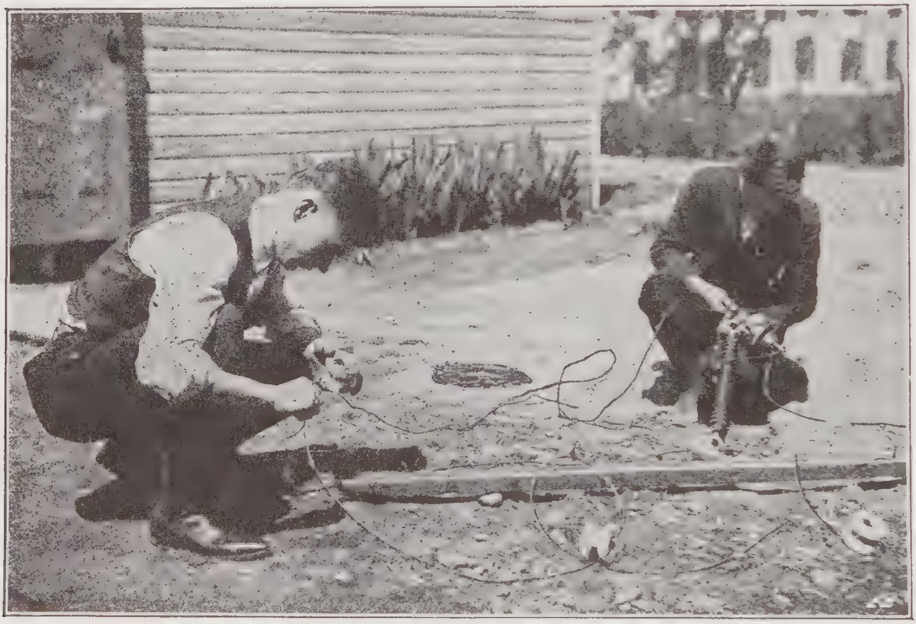


Fig. 9.

However, where long distances are wanted, it becomes necessary to use longer aërials.* The reason for this is that, to gain the highest maximum results in any radio transmitting or receiving circuit, the antenna oscillatory circuit down to earth should be able to vibrate at a frequency approximating its natural period. Hence, it is seen that for this reason, it is necessary to use a long aerial, having in consequence a long wave *natural period* in order to pick up efficiently such wave lengths as 12,000 or 15,000 meters. This is not the whole story, either, for another important factor is that the longer the

* See "Calculation and Measurement of Inductance." Chapters 13, 14 and 15.

aerial, the more energy will be picked up from the rapidly moving etheric wave front, as it passes along the antenna wires. This may be compared for analogy to the electromagnetic field. In a dynamo or motor you will recollect that the longer the wire, the more magnetic flux it will intercept in its rotation in the field, with a consequent



Here We See Two Earnest Radio Amateurs Preparing the Antenna. The Insulators Must Be Tied or Wired on Very Firmly to Withstand Wind Storms. The Spreaders and Metal Fittings Should Be Thoroly Painted.

greater potential produced in the moving conductor. In the case of radio transmission, the conductor is stationary, while the electrostatic field moves and thus cuts the wire, inducing an electric current in the wire. It is this induced current which operates the detector in the receiving set.

As a guide to the young radio designer, the accompanying graph chart (Fig. 9) is given, which shows the natural wave lengths of four-wire antenna of various heights and lengths. These values were computed from data given by Dr. Louis Cohen. A common rule for calculating approximately the wave length in meters of a simple antenna system, without any coils or other apparatus connected with

it, is to multiply the length of the flat-top, plus the length of lead-in wire to earth, in meters by 4.5. This rule applies to inverted "L" type aerials. It is also applicable to "T" type antenna, but here the length of wire considered in meters is the lead-in length to earth,

Up Goes the Antenna—the Radio Amateur's Heart Now Beats With Joy, for Soon He Will Be Listening to the Etheric Messages from Stations Hundreds and Even Thousands of Miles Away.

plus *one-half the length of the flat-top.* The factor 4.5 varies under different conditions, as, for instance, where metal roofs may change the natural capacity of the antenna. But it serves very well for approximation, and has been very extensively used.

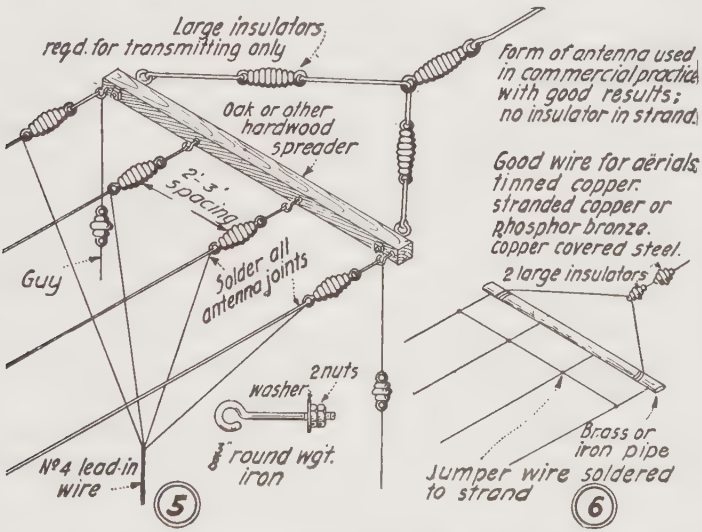
Details of Aerial Construction.

When it comes to discussing details of amateur aerial construction, one could almost write an encyclopedia of several volumes, for in traveling about the country, it is amazing to note the many different ideas followed in building antenna. This is so for many reasons, not simply because one Radio Amateur wishes to have something different from his fellow Amateur across the street, but in a great majority of cases his pocketbook controls the design. And so it is that instead of using beautifully molded ten-inch Electrose insulators on his aerial, you may perchance bunk into one of the greatest freaks of modern times, a real dyed-in-the-wool Amateur antenna—constructed from about six kinds of wire, including some good old iron hay-baling wire, and a variety of insulators that would win first prize in any freak photo contest, made from miscellaneous odds and ends, including near-beer bottles, porcelain cleats, waxed wooden rods, pieces of crockery and other choice bits of "backyard junk."

So it is seen that there is a wide latitude in ideas, and good ones, too, in many cases, let it be said, for building an experimental wireless of fair efficiency. Your average Radio Amateur does not care so much about the "looks" of his antenna as he does about the fact as to whether or not he can sit down in his little coop with his apparatus about 10 P. M. and hear "Carnarvon" calling one of his Britannic Majesty's cruisers lying off the Canadian coast! That's the life that cheers.

Figs. 5 and 6 show several practical and approved developments in aerial design, which are not only efficient, but simple as well, in their application. Fig. 5 shows a typical elevated aerial spreader, which may consist of a length of stout bamboo, or a very good spreader composed of cypress or oak sparring, about two inches square. The best shape for the spar is to make it about four inches broad at the center, so as to give it greater strength against bending. For ordinary work the Amateur usually winds several turns of wire around the spreader, and then fastens his insulators to it. A good construction, however, is afforded at very small cost by having a blacksmith (or else you can make them yourself) bend up a few eye-bolts, as shown in Fig. 5. These may be made from 3/8 inch round, wrought-iron bar, threaded at one end and provided with a washer and a nut or two. The iron and wood work on the aerial should be thoroughly

painted, of course, before erection, so as to withstand the weather. A heavy red or white lead paint is advised. If the antenna is to be used for "Receiving" only, four insulators are placed at both ends of the flat-top at the spreaders. Where the very highest efficiency is desired, extra insulators may be placed in the suspension ropes holding the spreader, as shown at X. This is the standard of aerial construction, but a much simpler form which has been extensively used in commercial practice, on ship stations particularly, is that shown in Fig. 6. Here no insulators are used in the flat-top part of the aerial proper, but they are placed in the main suspension ropes, as shown at X. This insulating scheme effectually insulates the aerial, of course, and a piece of brass or iron pipe may very well serve as a spreader,



connecting the wires of the flat-top to the pipe, by winding the ends of the wires around it. It is the best practice to run a jumper wire across the strands, soldering this thoroughly at the joints. This applies to the free end of the antenna; no jumper wire being required at the opposite end, where the lead-in rattails are led off. In any case all points in the aerial circuit through which radio frequency energy has to pass, *should be carefully soldered*, or else a very good design of clamp should be used, packing the cleaned wire joint with tin-foil before tightening the clamp. The jumper and rattail connections for inverted "L" and "T" type aerials are clearly shown in Figs. 1 and 2.

Kind of Wire to Use in Aerials.

"What kind of wire should I use for constructing my aerial?" "How many feet long?" and "What altitude?" are questions frequently repeated, and these are not simple ones, either. However, the Radio Experimental Fraternity may count itself lucky in the respect that the size of wire for the antenna is pretty well standardized. For Amateur antenna, it is common to use a wire corresponding in size to No. 14 B. & S. gage solid conductor. Where stranded cable is used, and which possesses a much lower *high frequency* resistance than a solid conductor of equal diameter (owing to its greater surface area, which is the only part of the conductor traversed by the radio frequency currents), then a seven-strand cable is commonly employed. Seven strands of No. 22 or 24 wire constitute a common size of cable for experimental work, while a heavier cable is used in building commercial and Government stations. There are several kinds of wire in use for aerial construction. Aluminum wire was used previously, but it is very difficult to make a good soldered joint with aluminum wire, and for several other reasons it has not been used very much in latter-day practice. A very good wire for amateur work is a plain solid copper conductor, No. 14 B. & S. gage, or heavier, which may or may not be tinned. A good stranded cable for this work is one comprising seven strands of tinned copper wire. Another standard cable is a seven-strand one composed of phosphor bronze stock, which is of course very strong and suitable for the extra long spans. Still another form of wire in use for experimental aerial construction is copper-clad steel wire, which possesses greater tensile strength than any other equal size electrical conductor. The radio-frequency currents pass through the outer copper jacket. Plain iron wire alone has been used, but is not very satisfactory.

Grounding Connections.

The matter of grounding antenna, especially of the elevated type, is very important, markedly so in the case of *thunder-storms.* Also the *Fire Underwriters'* rules have to be carefully heeded in this respect, which apply to every building on which *fire insurance* is carried. The safest method to follow in any event, for your own protection, as well as keeping in conformity with the Fire Underwriters' rules, covers the following recommendations for the *grounding of radio antenna.*

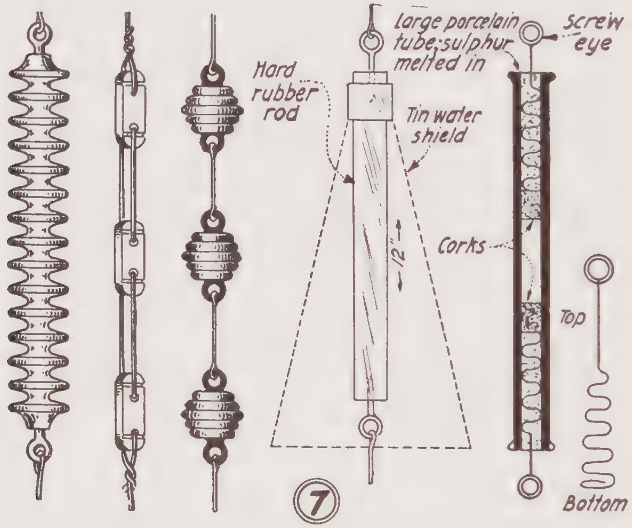
These regulations call for a ground wire connected to a first-class ground plate or pipe running down to damp earth, or to the street side of water mains in cities, this ground wire being composed of No. 4 B. & S. gage solid copper conductor. The ground wire connects to a grounding switch rated at 600 volts and 100 amperes. The regulations do not specify what size of lead-in conductors should be used, but it is apparent and obvious that if you intend to conduct a heavy static surge or induced charge from a thunder-storm down to earth through this massive switch and ground wire, that you certainly would not make a lead-in of No. 14 gage wire, like so many amateurs have been wont to do in past years. The right way to do this is to construct the lead-in wire of No. 4 B. & S. gage solid copper conductor or its equivalent in cross-sectional area, such as by employing two or more wires of smaller size stranded together. Good Radio Engineering practice calls for rattail leads brought down from each strand of the aerial to be of equal cross-sectional area to the aerial strands proper, and then bunching these rattail leads into the lead-in joint at the bottom of the fan-tail construction. All of these joints, as aforementioned, should be SOLDERED. The rattail leads should be brought into an aerial connector of some kind before being soldered, so as not to depend upon the solder alone for mechanical strength or electrical conduction.

The *Fire Underwriters'* rules further stipulate that this lightning ground and switch should be placed on the exterior of the building in all cases, and furthermore, that this *ground* which has just been described in detail, should be separated from the station ground. It is the usual practice in experimental radio stations to place the aerial grounding switch either on the window-sill or on the side of the window, and, of course, it should be covered with a metal or other box, so as to protect it from rain and snow. In running the ground wire down the side of a building, it need not be insulated and bare copper wire is generally employed. Fig. 4 shows one form of efficient ground for lightning protection or for the regular station grounding purposes. This ground is composed of a piece of galvanized chicken wire buried from three to five feet in the earth between two layers of charcoal. The depth to which the ground plate is buried will depend upon how dry the top soil is. *The ground plate must be placed in wet earth,* no matter if it has to be buried twenty feet deep, unless some provi-

sion is made to keep the earth in this vicinity moist, such as by daily watering, or else by allowing a waste pipe from some water system to empty over the spot.

TYPES OF MASTS.

When it comes to masts or towers for supporting the elevated type of antenna, there are many different styles. One of the latest



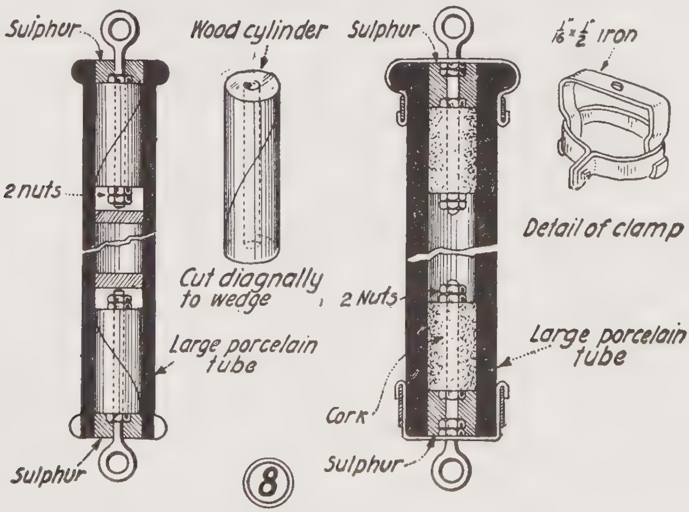
events in radio is the "Tree Aerial," as devised by Maj.-Gen. George O. Squier, which was described in detail, with special drawings, in the July, 1919, issue of the *Electrical Experimenter*.

This represents one form of natural elevation for supporting aerials or aerial conductors at a considerable altitude, and another one is the balloon or box kite. The average Radio Amateur does not care so much about details on the construction of radio masts, for in practically all cases he will follow his own intuition in making use of whatever material and facilities he may happen to have on hand. For example, some antenna masts used in the past have been of the latticed wood form of construction, while others of the iron pipe type have been erected to considerable heights. We remember one mast of iron pipe construction in the vicinity of New York City which rose to a height of 110 feet. For safety's sake, such a mast should not be

constructed with too small a pipe at the base, and for altitudes of 75 to 100 feet, the first and second base sections of the mast should comprise standard heavy wrought iron pipe not less than 3 to $3\frac{1}{2}$ inches in diameter. Needless to say, the iron pipe should be either galvanized or else thoroughly painted before erection, and very carefully guyed by stranded steel cables attached at 1/3, at 2/3 the altitude and at the top. Long guy wires should be split up into sections not exceeding 20 feet, by means of strain insulators, to minimize induction losses.

Aerial Insulators.

Various forms of commercial and home-made aerial insulators are shown in Figs. 7 and 8. Fig. 7 illustrates the commercial, fluted type of molded Electrose insulator, as well as the Electrose ball insulator. Where greater efficiency is desired, several of these insulators are connected in series to give a high resistance. Porcelain cleats are often used in constructing small experimental antenna, and serve



the purpose quite well. Another detail shown in Fig. 7 is an aerial insulator made from a piece of hard rubber, polished or unpolished (Bakelite is best), the two ends of which have threaded screw eyes as indicated. A tin or galvanized iron water shield is made to clamp

at one end of this hard rubber insulator in order to ward off rain, and thus keep the insulator in a better working condition during inclement weather. It is absolutely impossible to obtain any long distance results for *transmitting* or *receiving* with rain pouring down on the insulators; for a considerable amount of the energy induced in the aerial conductors will leak to earth through the water covering the insulators. The commercial radio companies have overcome this difficulty by placing cable shields on the antenna insulators in this fashion in a great many instances, and undoubtedly will use more of them as this fact is better appreciated. Figs. 7 and 8 show novel ideas for constructing antenna insulators from porcelain tubes. Of course, the small tubes are not of much use, generally speaking, but the large size tubes, measuring about 12 inches long by 1½ inches in diameter, are cheaply purchased, and make very good insulators. The main question here is "How can the screw-eyes be securely anchored?" and several suggestions are given in the drawing herewith. In one case the screw-eyes have their lower ends twisted spirally with the largest diameter at the base, so as to hold firmly in molten sulphur; or the screw-eye may be held by slotted wooden blocks cut so as to expand and wedge against one another inside the tube. Fig. 8 shows a detail drawing for making a pair of brass or iron clamps which will make a very substantial aerial insulator from any stout porcelain tube.

In closing, it may be said that the Amateur Radio man will learn much by close observation and the application of common sense and everyday electrical technique to his antenna structures. Don't use faulty lead-in insulators to bring the aerial current into your radio shack—buy a good one, even though it costs a few dollars. An excellent one is that made of molded Electrose, with threaded tightening flanges. A hole drilled through the center of a piece of glass, hard rubber or Bakelite sheet, at least one foot square, makes a very excellent lead-in insulator. Don't tie your aerial so tight that in a wind-storm it will break at the first swing; suspend one end by a counter-balance weight or else by springs, so that the flat-top can expand at least 5 to 10 feet in a 100- to 150-foot span. Watch your aerial's behavior in your first wind-storm and you will learn more than by reading a dozen books on the subject.

CHAPTER XIII.

The Calculation and Measurement of Inductance.

ALTHO a considerable amount of data has been published on the subject of *Inductance*, very little has been said regarding its calculation and measurement in a simple enough manner to enable the experimenter to determine the inductance values of coils which he has about his station and laboratory. It is therefore the purpose of this discussion to show as clearly as possible the method of determining the inductance of a given coil, both of the single and multi-layer types.

Firstly, it is well known that whenever an electric current passes thru a conductor a magnetic field is produced about that conductor, Fig. 1, and the intensity of the field depends upon the current flowing thru the wire. Those magnetic lines of force about the wire produce an e.m.f., passing in the opposite direction to that of the imprest e.m.f.

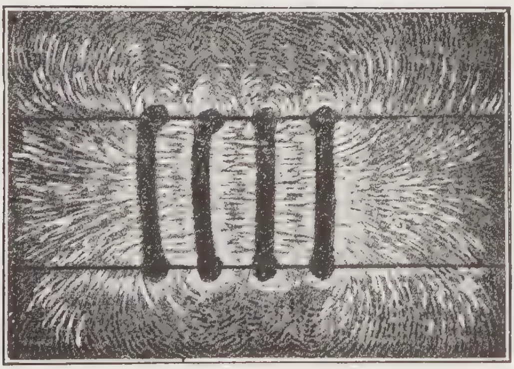


Fig. 1. Appearance of magnetic field about coil of wire.

The effect of this is to counteract the imprest current, thus decreasing its value. This counter e.m.f., acting upon the whole electrical system is called "self inductance" and every conductor irrespective of its shape, length or size, has some self-inductance. However, the amount of inductance of the conductor depends upon several factors, namely: shape, length, diameter of conductor and the amount of current flowing thru the wire. This last term is usually eliminated in actual inductance calculations, especially in coils which are connected in high frequency oscillating circuits.

Since the magnetic effect of a conductor carrying an electric current is increased when the wire is formed into a circle and since the self-inductance depends upon the number of magnetic lines of force produced, it is self-evident that a circular conductor of the same length and same size has a larger self-inductance value than a straight wire. It is readily seen therefore why circular coils are employed instead of long, single conductors. With compact coils the magnetic field is more concentrated.

The *Henry* is the unit of inductance. A circuit is said to have an inductance of one henry, when the current is changing at the rate of one ampere per second and inducing a pressure of one volt in the circuit. One henry is equal to 10^9 or 1,000,000,000 (centimeters) C.G.S. electromagnetic units (C.G.S.) in the centimeter-gram-second system; 1 milli-henry = .001 henry or 10^6 centimeters. Henries times 10^9 = inductance in cms., and inductance in cms., divided by 10^9 gives the result in henries. A coil is said to have 1 C.G.S. unit of inductance when 1 C.G.S. unit of current flows thru 1 turn, producing 1 line of force. Let the current in amperes be I, number of turns in coil T, and I_0 number of lines of force due to coil, then we have for the henries of inductance of the coil the expression:—

$$L = \frac{I_0 \times T}{10^8 \times I};$$

The self-inductance of a single, straight round wire can be determined by the formula:—

$$L = 2l \left[2.3026 \log_{10} \frac{4l}{d} - 1 \right] \qquad (1)$$

where L = inductance in centimeters.
l = length of wire in centimeters.
d = diameter of wire in centimeters. Suppose it is required to find the inductance of a single antenna wire whose length is 400 feet and diameter .08 inch. Converting the above units into centimeters and substituting in formula No. 1, we get:—

$$L = 2 \times (400 \times 30.48) \left[2.3026 \log_{10} \frac{4(400 \times 30.48)}{.08 \times 2.54} - 1 \right]$$
$$= 24384\ [2.3026 \times 5.38021 - 1]$$
$$= 27{,}766\ \textit{cm. or } .000027766\ \textit{henry.}$$

It is therefore possible with the above formula to determine the self-inductance of a single antenna wire. The result obtained with this formula is approximate as it does not take into consideration several factors such as curved or bent portions of the lead-in, etc. The surrounding objects about the wire have an appreciable effect upon the inductance also. However, for approximate results the above equation will be found useful.

The common formula given in text-books for computing the inductance of coils having a length *at least* 20 or more times the diameter is given here:

$$L = \frac{10{,}028 \times R^2 \times T^2}{10^{11} \times l}; \qquad (2)$$

Where L is in henries; R the mean radius of coil in inches; T the total turns in coil; l the axial length of coil in inches. Result in cms. = henries $\times\ 10^9$. For coils containing iron cores the inductance must be multiplied by the permeability, found in all magnetization tables.

The most common form of inductance that the amateur is familiar with is that of a straight cylinder with a certain number of turns on it. The inductance of such a coil can be found by substituting its various dimensions in the following expression:—

$$L = \frac{(5 \times d \times N)^2}{S + \frac{d}{3}} \qquad (3)$$

Where: L = inductance in centimeters
d = diameter of coil in inches
N = total number of turns
S = length of coil in inches.

Example:—Suppose it is necessary to find the inductance of a coil whose dimensions are as follows: 12 inches long, 3 inches in diameter with 250 turns of No. 18 wire.

Substituting the given values in the above equation we get

$$L = \frac{(5 \times 3 \times 250)^2}{12 + \frac{3}{3}} = 1{,}081{,}730 \ cms.$$

The above coil has an inductance of 1,081,730 cms. and if the

result is desired in microhenrys it is only necessary to divide the answer by 1,000, thus giving 1,081 microhenrys.

The above formula will hold true when the coil is very long (length 20 times diameter, etc.) and when the answer is not required to be very accurate. The formula given below will prove more accurate for a coil whose diameter is greater than its length. This equation is by Dr. A. Russell:

$$L = (\pi DN)^2 l \left[1 - \frac{4}{3\pi} \frac{D}{L} + \frac{1}{8} \left(\frac{D}{l} \right)^2 - \frac{1}{64} \left(\frac{D}{l} \right)^4 \right] \qquad (4)$$

Where: L = inductance in centimeters
D = diameter of coil in cm.
N = number of turns per cm.
l = the length of coil in cm.

Altho the above formula is quite accurate for calculating the inductance of a coil of any length, there are still two other formulae which are very accurate for any size coil, even those having a length of one-tenth the diameter or a single turn.

The first of these is due to Nagaoka, who has developed a very simple equation as follows:

$$L = 4\pi^2 a^2 n^2 bk; \qquad (5)$$

Where:—L = inductance of coil in centimeters
a = radius of coil to center of wire, in centimeters (mean radius)
n = number of turns of wire per cm. length of coil
b = length of coil in centimeters
k = a constant.

The only difficulty encountered in the use of this well-known formula is that involved in the constant, k, the value of which must be obtained from a table. The table gives correction factors for different lengths and diameters of solenoids. It does not take into con-

sideration the so-called *current sheet effect,* which is the effect due to the leak between successive turns of wire. (*See end of this chapter.*)

For accurate calculations the formula is one of the best that one can employ. Those readers interested in this formula and tables can refer to pages 119, 224 and 225 of the *Bulletin of the Bureau of Standards,* Vol. 8, No. 1, by Rosa and Grover, 1912, entitled: Formulas and Tables for the Calculation of Mutual and Self-Inductance. (Revised.)

A new universal formula for determining the inductance of any coil, absolutely irrespective of its size and shape, has been deduced by Professor Morgan Brooks. The equation which he has developed is applicable to all sizes of solenoids. This formula has been carefully

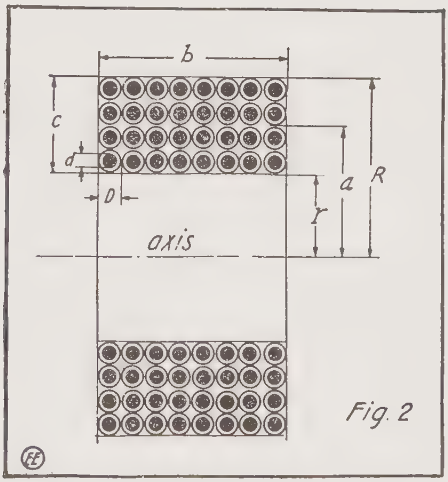


Fig. 2

checked for coils whose inductance was measured and also calculated by other standard precision formulae such as that of Stefan and Kirchhoff for coils of but a single turn. It was found that the results obtained differed infinitesimally from those obtained with Nagaoka's formula.

Two forms of the Brooks universal formula are herewith given.

One in which the dimensions are in centimeters and another in which the English units are used. Both give results in henries.

$$L = \frac{Cm^2}{b + c + R} \times \frac{F' F''}{10^9} \text{ (centimeter units)} \tag{6}$$

$$L = \frac{0.366 \left(\frac{Ft}{1000}\right)^2}{b + c + R} \times F' F'' \text{ (English units)} \tag{7}$$

Where:—L = inductance in henries
a = mean radius of winding
b = the axial length of the coil
c = the thickness of winding; for single turns use (d) dia. of wire in inches
R = the outer radius of the winding
Cm = indicates the length of the conductor in centimeters
Ft = the length of the conductor in feet and Ft/1000 = thousands of feet
N = total number of turns in the winding, whence
Cm = $2\pi aN$ when (a) is in centimeters and

$$\frac{Ft}{1000} = \frac{2\pi\, aN}{12{,}000} \text{ when (a) is in inches.}$$

In (7) the conductor length is in thousands of feet and the coil dimensions in inches while 0.366 is the conversion factor. F′ and F″ are empirical coil-shape factors, dependent upon the relative and independent of the absolute dimensions of the winding. The values for these two factors are obtained by the following expressions:

$$F' = \frac{10b + 12c + 2R}{10b + 10c + 1.4R} \tag{8}$$

$$F'' = .05 \log_{10} \left(100 + \frac{14R}{2b + 3c}\right) \tag{9}$$

The notation of the different functions used in the first two expressions can be more readily understood by referring to Fig. 2, which is a cross section of a solenoid. The curves of Fig. 3 enable one to select directly the value of the product F′ F″, for a wide variety of windings, from those having a length about three times the mean

diameter to those whose length is but 1/300th the diameter. These shape factors given by Fig. 3 are relative functions only, as becomes apparent and are not in inches or cms., but serve for computations in either system. The Brooks formula is accurate to a small fraction of 1 per cent in most all instances, even for coils of a single turn. In the case of a tested (single turn) coil the calculated value of inductance by this formula was only—0.88 per cent in error, which of course represents the extreme test for any formula of this nature. Solenoids containing any number of layers are covered by it also.

The direct reading inductance curves at Fig. 4 have been calculated by the author from the Brooks equation (No. 6) and will undoubtedly prove useful to the radio and electrical experimenter as

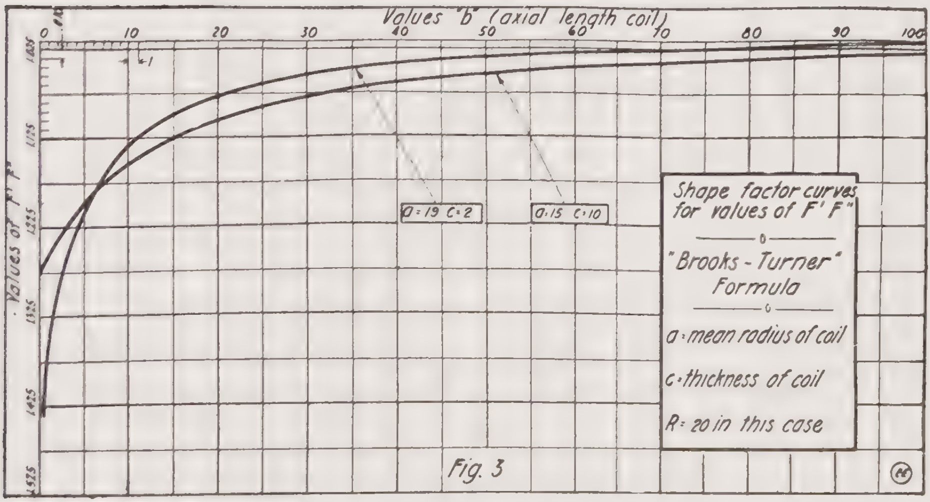
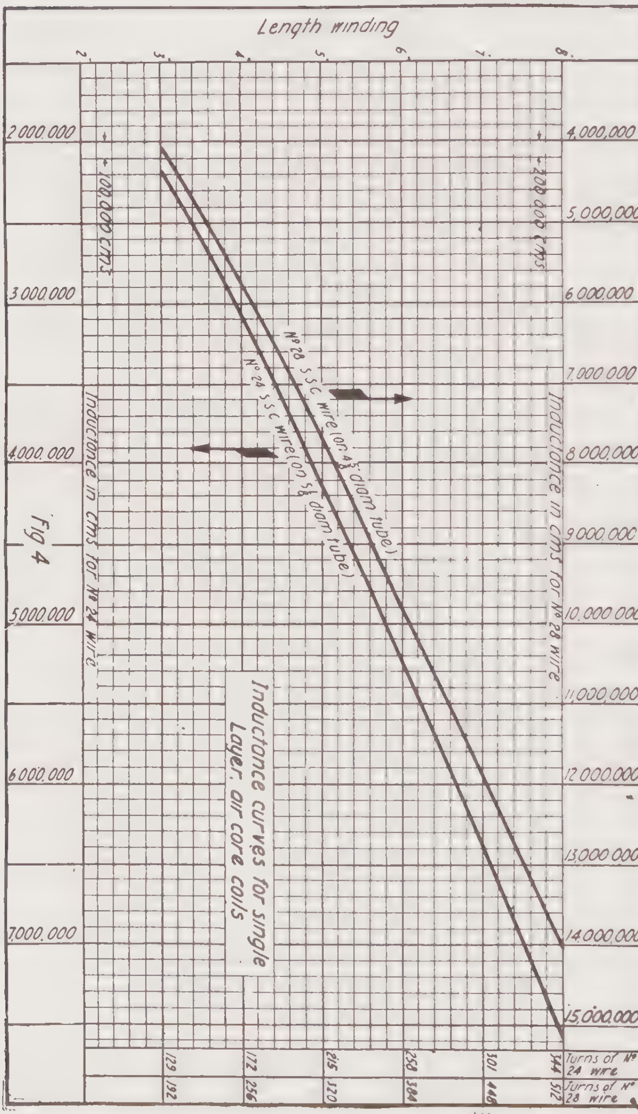


Fig. 3

these values have not been given before to his best knowledge. The two windings have been chosen so that one may select suitable length coils for use in building small and medium size loose couplers, tuning coils and variometers.

For the inductance values of larger size coils suitable for extra long wave reception and the method of figuring the desired amount of tuner inductance, with respect to the electrical constants of the antenna, the reader is referred to the article by Mr. C. Ballantine, entitled *"The Design of Large Radio Receiving Transformers"* in the February, 1917, issue of the *Electrical Experimenter*.



Direct Reading Curves from which the exact inductance of loose coupler and tuning coil windings can be easily determined without calculation.

In using the Brooks universal formula, the factors, F′ F″, may be disregarded for long coils and for approximate results the formula reduces to:—(L in henries).

$$L = \frac{Cm^2}{(b + c + R)10^9}; \tag{10}$$

$$Or\ L\ in\ cms. = \frac{Cm^2}{(b + c + R)}; \tag{11}$$

The equation can still be reduced for very long coils, since "b" becomes so large as compared with "c" and "R," so that equation (10) becomes:—(L in henries).

$$L = \frac{Cm^2}{b \times 10^9}; \tag{12}$$

$$Or\ L\ in\ cms. = \frac{Cm^2}{b} \tag{13}$$

The above expression will be accurate within the limits of approximation with coils whose length is ten times the diameter. It may be used to advantage in calculating the inductance of spiralled antenna.

In order to become more familiar with the use of Brooks' formula, we will illustrate it with a typical problem. Let us determine the inductance of a variometer coil whose length is one inch, diameter 6 inches and wound with a single layer of No. 20 double cotton covered wire.

$$\left(\frac{Ft}{1000}\right)^2 = \left(\frac{2\pi\, a\, N}{12{,}000}\right)^2 = \left(\frac{2 \times 3.1416 \times 3.016 \times 25}{12{,}000}\right)^2 = \cdot 001521$$

$$L = \frac{0.366\ (.001521)}{4.064} \times F' F''$$

Substituting the values for F′ F″ in equations (8) and (9) we obtain for F′ (1.12) and F″ (1.03995). Solving the above we obtain for L = .000198 henry or 198,050 centimeters of inductance.

It will be observed that the shape correction factors are very small and the larger the coil becomes the nearer will they approach

unity; for this reason they may be neglected for coils whose diameters are one-tenth that of their length.

For long inductances, such as those used in the regenerative Audion circuits for receiving undamped waves, the above formula is particularly useful. As an example, the inductance of a long wave loading coil, consisting of a single layer of No. 28 S.S.C. magnet wire, wound on a cardboard tube 28 inches long (26 inches of winding) and $5\frac{5}{8}$ inches outside diameter was ascertained to be 76,355,400 cms. Using this coil in series as a loader, with a 4 wire, 500 ft. flat-top. inverted "L" antenna, 100 ft. high, and with a loose coupler primary having 9,400,000 cms. of inductance, the wave length capacity figures out to about 22,900 meters; sufficient for practically all experimental requirements.

The formulæ given herein for calculating the inductance of coils is for the *current-sheet* value, and apply accurately only to a winding or infinitely thin metal strip, which completely covers the solenoid, the successive turns being supposed to meet at the edges without making electrical contact, and so realizing a uniform distribution of current over the surface. If we have a winding of insulated wire or of bare wire wound in a screw thread, we may have a greater or less self-inductance than that given by the current sheet formula. This depends upon the ratio of the diameter of the wire to the pitch of the winding. Taking L for the actual self-inductance of a coil and Ls for the current-sheet value *as found by any of the formulae herein cited*, we obtain the expression:

$$L = Ls - DL;$$

The quantity DL is found by solving the following equation:

$$DL = 4\pi \times a \times n\,(A + B);$$

Wherein

a = mean radius of coil in cms.
n = whole number of turns in coil.
π = 3.1416.

While A and B are constants to be taken from the accompanying tables I and II. The correction term A is dependent upon the size of

NAGAOKA'S TABLE OF VALUE OF THE END CORRECTION "K" AS A FUNCTION OF THE RATIO; DIAMETER DIVIDED BY LENGTH.

Diameter / Length	K	Δ_1	Δ_2	Diameter / Length	K	Δ_1	Δ_2
0.00	1.000 000	−4231	+24	0.45	0.833 723	−3160	+21
.01	.995 769	−4207	26	.46	.830 563	−3139	22
.02	.991 562	−4181	24	.47	.827 424	−3117	21
.03	.987 381	−4157	25	.48	.824 307	−3096	21
.04	.983 224	−4132	25	.49	.821 211	−3075	21
0.05	0.979 092	−4107	+25	0.50	0.818 136	−3054	+21
.06	.974 985	−4082	26	.51	.815 082	−3033	21
.07	.970 903	−4056	24	.52	.812 049	−3012	21
.08	.966 847	−4032	24	.53	.809 037	−2991	20
.09	.962 815	−4008	26	.54	.806 046	−2971	21
0.10	0.958 807	−3982	+25	0.55	0.803 075	−2950	+20
.11	.954 825	−3957	24	.56	.800 125	−2930	20
.12	.950 868	−3933	23	.57	.797 195	−2910	20
.13	.946 935	−3910	26	.58	.794 285	−2890	20
.14	.943 025	−3884	27	.59	.791 395	−2870	20
0.15	0.939 141	−3857	+23	0.60	0.788 525	−2850	+19
.16	.935 284	−3834	23	.61	.785 675	−2831	19
.17	.931 450	−3811	26	.62	.782 844	−2812	20
.18	.927 639	−3785	24	.63	.780 032	−2792	19
.19	.923 854	−3761	24	.64	.777 240	−2773	19
0.20	0.920 093	−3737	+24	0.65	0.774 467	−2754	+19
.21	.916 356	−3713	24	.66	.771 713	−2735	19
.22	.912 643	−3689	25	.67	.768 978	−2716	19
.23	.908 954	−3664	23	.68	.766 262	−2697	18
.24	.905 290	−3641	25	.69	.763 565	−2679	18
0.25	0.901 649	−3616	+23	0.70	0.760 886	−2661	+18
.26	.898 033	−3593	24	.71	.758 225	−2643	19
.27	.894 440	−3569	23	.72	.755 582	−2624	17
.28	.890 871	−3546	24	.73	.752 958	−2607	18
.29	.887 325	−3522	24	.74	.750 351	−2589	18
0.30	0.883 803	−3498	+22	0.75	0.747 762	−2571	+17
.31	.880 305	−3476	24	.76	.745 191	−2554	17
.32	.876 829	−3452	23	.77	.742 637	−2537	18
.33	.873 377	−3429	23	.78	.740 100	−2519	17
.34	.869 948	−3406	22	.79	.737 581	−2502	16
0.35	0.866 542	−3384	+24	0.80	0.735 079	−2486	+19
.36	.863 158	−3360	22	.81	.732 593	−2467	16
.37	.859 799	−3338	23	.82	.730 126	−2451	16
.38	.856 461	−3315	22	.83	.727 675	−2435	16
.39	.853 146	−3293	23	.84	.725 240	−2419	17
0.40	0.849 853	−3270	+22	0.85	0.722 821	−2402	+16
.41	.846 583	−3248	23	.86	.720 419	−2386	16
.42	.843 335	−3225	21	.87	.718 033	−2370	15
.43	.840 110	−3204	21	.88	.715 663	−2355	16
.44	.836 906	−3183	23	.89	.713 308	−2339	17

NAGAOKA'S TABLE OF VALUE OF THE END CORRECTION "K" AS A FUNCTION OF THE RATIO; DIAMETER DIVIDED BY LENGTH.
(Continued.)

Diameter / Length	K	Δ_1	Δ_2
0.90	0.710 969	−2322	+ 14
.91	.708 647	−2308	16
.92	.706 339	−2292	15
.93	.704 047	−2277	16
.94	.701 770	−2261	14
0.95	0.699 509	−2247	+ 15
.96	.697 262	−2232	15
.97	.695 030	−2217	15
.98	.692 813	−2202	14
.99	.690 611	−2188	14
1.00	0.688 423	−10726	+ 344
1.05	.677 697	−10382	330
1.10	.667 315	−10052	316
1.15	.657 263	−9736	303
1.20	.647 527	−9433	290
1.25	0.638 094	−9143	+ 278
1.30	.628 951	−8865	266
1.35	.620 086	−8599	255
1.40	.611 487	−8343	244
1.45	.603 144	−8099	236
1.50	0.595 045	−7863	+ 224
1.55	.587 182	−7639	215
1.60	.579 543	−7424	208
1.65	.572 119	−7216	198
1.70	.564 903	−7018	190
1.75	0.557 885	−6828	+ 184
1.80	.551 057	−6644	176
1.85	.544 413	−6468	170
1.90	.537 945	−6298	161
1.95	.531 647	−6137	154
2.00	0.525 510	−11809	+ 580
2.10	.513 701	−11229	539
2.20	.502 472	−10690	499
2.30	.491 782	−10191	465
2.40	.481 591	−9726	434

Diameter / Length	K	Δ_1	Δ_2	Δ_3
2.50	0.471 865	−9292	+ 405	
2.60	.462 573	−8887	378	
2.70	.453 686	−8509	355	
2.80	.445 177	−8154	330	
2.90	.437 023	−7824	312	
3.00	0.429 199	−7512	+ 293	
3.10	.421 687	−7219	275	
3.20	.414 468	−6944	260	
3.30	.407 524	−6684	245	
3.40	.400 840	−6439	230	
3.50	0.394 401	−6209	+ 220	
3.60	.388 192	−5989	207	
3.70	.382 203	−5782	195	
3.80	.376 421	−5587	186	
3.90	.370 834	−5401	174	
4.00	0.365 433	−5227	+ 168	
4.10	.360 206	−5059	161	
4.20	.355 147	−4898	152	
4.30	.350 249	−4746	141	
4.40	.345 503	−4605	138	
4.50	0.340 898	−4467	+ 134	
4.60	.336 431	−4333	125	
4.70	.332 098	−4208	118	
4.80	.327 890	−4090	115	
4.90	.323 800	−3975	102	
5.00	0.319 825	−18321	+2227	−397
5.50	.301 504	−16094	1830	−306
6.00	.285 410	−14264	1524	−241
6.50	.271 146	−12740	1283	−193
7.00	.258 406	−11457	1090	−153
7.50	0.246 949	−10367	+ 937	−127
8.00	.236 582	−9430	810	−104
8.50	.227 152	−8620	706	− 86
9.00	.218 532	−7914	620	
9.50	.210 618	−7294		
10.00	0.203 324			

the bare wire, having diameter "d," as compared with the pitch "P" of the winding, or on the value of the ratio $\frac{d}{P}$. The two values must be in units of like denomination, i.e., either in cms. or in inches. When the value $\frac{d}{P}$ becomes less than 0.58, A is negative and in such cases when the numerical values of A are greater than those of B, which is always positive, the correction DL becomes negative, and hence L will be greater than Ls.

The correction in the inductance value for high frequency circuits may be made as follows: Subtract from the inductance L, as above corrected, one-half the length of the conductor on the coil in centimeters.

TABLE I

Values of Correction Term "A," depending on the ratio $\frac{d}{P}$ or the Diameter of Bare and Covered Wire on the Coil.

$\frac{d}{P}$	A	$\frac{d}{P}$	A	$\frac{d}{P}$	A
1.00	0.5568	.80	0.3337	.60	0.0460
.99	.5468	.79	.3211	.59	.0292
.98	.5367	.78	.3084	.58	.0121
.97	.5264	.77	.2955	.57	–.0053
.96	.5160	.76	.2824	.56	–.0230
.95	.5055	.75	.2691	.55	–.0410
.94	.4949	.74	.2557	.54	–.0594
.93	.4842	.73	.2421	.53	–.0781
.92	.4734	.72	.2283	.52	–.0971
.91	.4625	.71	.2143	.51	–.1165
.90	.4515	.70	.2001	.50	–.1363
.89	.4403	.69	.1857	—	———
.88	.4290	.68	.1711	.50	–.1363
.87	.4176	.67	.1563	.45	–.2416
.86	.4060	.66	.1413	.40	–.3594
.85	.3943	.65	.1261	.35	–.4928
.84	.3825	.64	.1106	.30	–.6471
.83	.3705	.63	.0949	.25	–.8294
.82	.3584	.62	.0789	.20	–1.0526
.81	.3461	.61	.0626	.15	–1.3403
.80	.3337	.60	.0460	.10	–1.7457

TABLE II

Values of the Correction Term "B," depending on the Number of Turns of Wire on the Single Layer Coil

No. of Turns	B	No. of Turns	B
1	0.0000	50	0.3186
2	.1137	60	.3216
3	.1663	70	.3239
4	.1973	80	.3257
5	.2180	90	.3270
6	.2329	100	.3280
7	.2443	125	.3298
8	.2532	150	.3311
9	.2604	175	.3321
10	.2664	200	.3328
15	.2857	300	.3343
20	.2974	400	.3351
25	.3042	500	.3356
30	.3083	600	.3359
35	.3119	700	.3361
40	.3148	800	.3363
45	.3169	900	.3364
50	.3186	1000	.3365

CHAPTER XIV.

The Calculation and Measurement of Inductance.

(*Continued*)

IN the last chapter we considered the *calculation of inductance* while in the present one we shall confine ourselves to the *measurement of inductance.*

There are several methods which have been adopted for the measurement of this important quantity and the most practical and simple ones will be discussed here.

The inductance of a coil which is connected in a low frequency circuit can be determined by connecting it as indicated in Fig. 1. A is the source of alternating current frequency of which is known, R a variable resistance or variable impedance coil for controlling the current, Am and Vm are A.C. ammeter and voltmeter while L is the coil, the inductance of which is to be measured. The connections of the various instruments should be properly made. In the act of measuring, care should be taken to see that the meters indicate maximum deflection before opening the circuit.

The observed indications of the meters are then substituted in the following equation:

$$L = \frac{1}{\omega} \sqrt{\frac{E^2 - I^2 R^2}{I^2}}$$

Where:

L = Inductance of the coil in henries

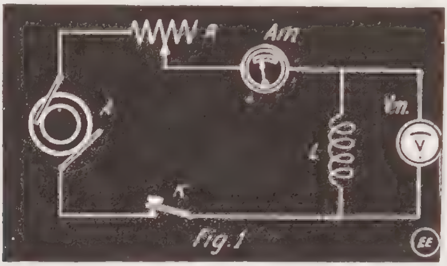
E = Indicated voltage

I = Indicated amperage

R = Resistance of the coil in ohms; this value can be obtained by measuring it with a Wheatstone bridge.

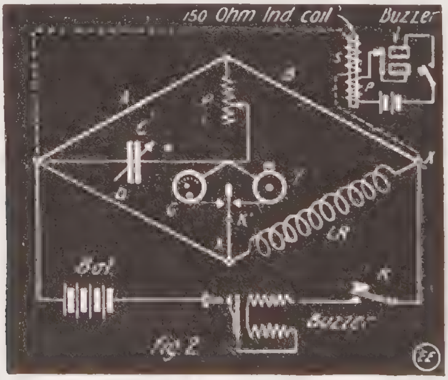
ω = Angular velocity which is equal to (3.1416x2) $\times$ the frequency. If an alternating current generator is used the frequency would be $f = \frac{NS}{120}$. N being the number of poles of the alternator and S the number of revolutions per minute.

The above method is applicable in measuring the inductance of coils up to .02 henries, when employing frequency of 25 to 60 cycles, if a higher frequency is used such as 500 cycles, the scheme can be



used to advantage to measure the inductance as high as .004 henries. The latter coils, however, are those which are of the air core type, while those of the former are of the magnetic core type, such as employed in impedance or reactance coils.

The inductance of magnetic core coils is sometimes very important, especially when it is desired to determine the total impe-



dance of the primary side of a transformer which is connected in series with a variable resistance. The expression for such a circuit is:

$$Z = \sqrt{R^2 + \omega^2 L^2}$$

Where:

Z = total impedance

R = the resistance of the total electrical circuit (primary)

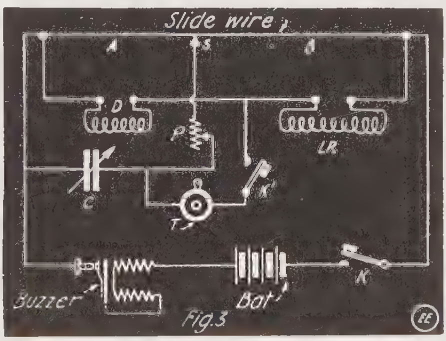
ω = angular velocity ($2\pi f$)

f = frequency in cycles per second

L = inductance.

We shall next consider the measurement of inductance by a Wheatstone bridge, which is usually in the experimenter's laboratory. The schematic connections of the Wheatstone bridge as used in this measurement is shown in Fig. 2, while Fig. 3 shows the connections of a slide wire bridge.

Referring to Fig. 2, the resistance arm D should be a plug resistance, having a range from 0 to 20,000 ohms and the condenser C should be of the variable air-dielectric type, while the series variable



resistance P should be about 4,000 ohms for its maximum. The coil the inductance of which is to be determined is placed across the terminals marked XX of the bridge. The resistance of the coil is to be known, and this is obtained by measuring it on the same or a different bridge. Across the arms of the bridge is shunted a high frequency buzzer in series with several batteries and key K, while across the neutral point, the resistance P and galvanometer G, telephone receiver T and key K^1 are connected as indicated. Where the bridge arms or inductance have a high resistance, it is necessary to employ a buzzer inductively connected thru a telephone or medical induction coil as indicated by the dotted lines in Fig. 2.

The first object in the procedure is to obtain a steady balance on the bridge. The resistance P and condenser C being removed, the resistance arms ABD are varied until a minimum sound is heard in the receiver T, while the bridge is being excited by the interrupted

current of the buzzer. As soon as this balance is obtained, the resistance P and capacity C are reinserted. It will be found that when the galvanometer key is first closed and then the battery key, the galvanometer coil is found to be in motion, thus indicating that the balance is not precise, but this may be annulled by varying P and C until the kick of the galvanometer is entirely eliminated. A still finer balance can be obtained by using the (75 ohm) telephone receiver instead of the galvanometer. It should be remembered that when using the galvanometer for the indicating device that more battery should be employed as the time-constant of the galvanometer is slow, compared with that of the vibration of the buzzer.

Having observed the values of the arms of the bridge, capacity of condenser and resistance of P, they are then substituted in the following equation, which is a relation of inductance of the coil to that of the other factors, thus we have:

$L = C\ [P(R+D)+AR]$

L = Inductance of coil in micro-henry

C = Capacity of condenser in microfarads when point of balance is obtained

P = Resistance in ohms

R = Resistance of coil, the inductance of which is to be determined.

AD = Resistance of arms of bridge.

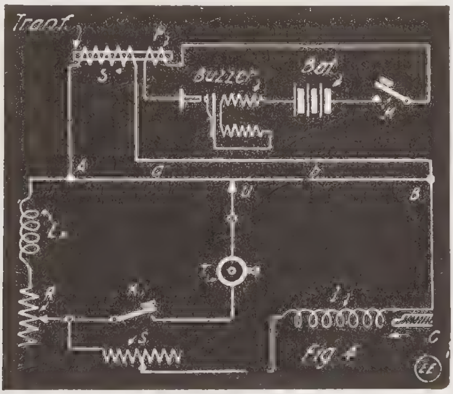
[*When it is desired to have the unit of measurement in millihenrys, it is necessary to divide the result obtained by* 1,000; *or by* 1,000,000 *to reduce it to henrys.*]

The same procedure should be followed when using the slide wire type of bridge, the only change in operation being to move the slider S along the wire until resonance is obtained (see Fig. 3). The known resistance D should be of the non-inductive box type and should have a capacity of 40,000 ohms, varying at intervals of 100 to 200 ohms per plug.

Another method of measuring inductance is by means of the Siemens and Halske inductance bridge.* A wiring diagram of this type of instrument is shown in Fig. 4. It consists of a standard slide wire bridge shunted by a buzzer, transformer (see Fig. 2, also) and battery. The arms of the bridge are linked with the unknown in-

* See article by Dr. A. N. Goldsmith in *Wireless Age* for April, 1914.

ductance Lx, which is connected in series with a small variable resistance R. An additional variable resistance S is connected as shown and usually consists of a plug resistance box. This resistance ranges from one-tenth to five-tenths of an ohm. The standard inductance I is of special construction, it consists of a small coil into the center of which an iron core C of suitable shape is placed. The



core is placed on a movable rack so as to permit the core to be moved in or out of the coil at will. Thus by allowing the core to be wholly in the coil the inductance will be maximum; in this manner the inductance of the coil is made variable by means of this ingenious variable core arrangement. The iron of the core C is made from a number of iron wires finely divided and imbedded in paraffin wax. In this way the core is made to have very small alternating field losses, such as hysteresis and eddy currents. The alternating current for the bridge is derived from a buzzer linked across the bridge as indicated. The indicating device consists of a telephone receiver.

The general procedure in measuring inductance with this type of bridge is as follows: The alternating current source is connected so as to excite the circuit and then closing the telephone receiver switch K^1, the slider U is adjusted to obtain as nearly a minimum sound in the receiver as possible. In order to further reduce the intensity of the sound the resistances R and S are adjusted, also the core C of the standard inductance coil I. When the position of re-

sonance is obtained, the inductance of the unknown coil Lx is derived by substituting the observed values in the following expression:

$$Lx = \frac{a}{b} I$$

Where:

LX = Inductance of the unknown coil
a = Length of one side of wire
b = Other length of wire
I = Inductance of the known coil.

It should be remembered that in using the known inductance that it is necessary at first to standardize this coil with respect to

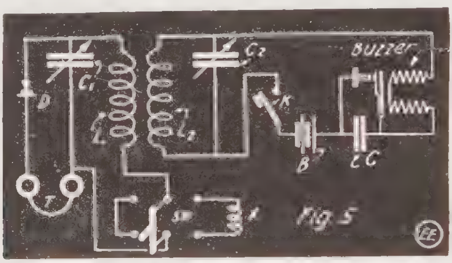


Fig. 5

every position of the iron core within the coil, before it is possible to use it as a standard. In actual practise this coil is supplied with a calibration curve showing the value of the inductance with every position of the core. The measurement of inductance with this method is accurate within one-half of one per cent.

Having described the general method of measuring inductance by means of the various methods of the employment of the Wheatstone bridge, we will now discuss another well-known method of performing this measurement. This is dependent upon the resonance of two coupled circuits. In utilizing this scheme there are required two standard calibrated variable condensers, one standard inductance, an exciting apparatus such as a buzzer, and a receptor consisting of a crystal detector and telephones and connected as shown in Fig. 5. The procedure with this arrangement is this: the circuit L_2C_2 is excited by means of the buzzer and the coupled circuit L_1C_1 is tuned to resonance by noting the maximum sound in the receptor circuit. In this connection the switch is so placed that inductance L_1 only is in the circuit. The position of resonance of the condenser scale is noted

and marked as Ca. The switch is then changed so as to connect the unknown inductance X in the circuit and the resonance position is again obtained and call this position on the condenser scale Cb. Since resonance existed in the coupled circuit, their relation can be expressed as

$$C_a L_2 = L_1 C_1$$

which is the expression for the first position of resonance, but as soon as the unknown coil is added then we have

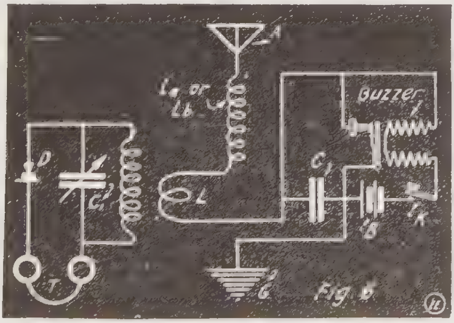
$$(L_1 + X)\ C_1 = L_2\ C_b$$

Solving for the unknown inductance X we have

$$X = \frac{L_2\ (C_b - C_a)}{C_1}$$

which gives the value of the unknown inductance in terms of the capacity of one of the condensers and the standard inductance. It is advisable when using a buzzer exciter that it should be of such construction as to produce a fairly high note.

It sometimes happens that the inductance of an antenna is required and for this determination the following data will be useful:



Inasmuch as inductance is a factor of wave-length of the antenna system and since it possesses capacity with respect to the earth, it seems therefore possible to determine one of these units if the other is at hand. The well-known formula for expressing the capacity of

an aerial in terms of its wave length and inductance is herewith given:

$$C = \frac{\lambda^2}{36\pi^2 \, 10^{16} \, L}$$

Where:

C = Capacity of the antenna system in farads

L = Inductance in henrys

λ = Wave lengths in meters.

Or, solving L in terms of its capacity and wave length, we get

$$L = \frac{\lambda^2}{36\pi^2 \, 10^{16} \, C}$$

The connections for this measurement are indicated in Fig. 6. The antenna is excited by means of a buzzer which is shunted with a condenser C. This is used for charging and discharging the antenna. La and LB are two known inductance coils which are inserted at different times, L is a coupling coil which consists of one or two turns of wire. This coil is placed in proximity to the coil which constitutes the inductance of a wave meter, coupled with a variable condenser C_1 and a responsive device D and T, which are a crystal detector and telephone.

In the actual measurement the antenna system is excited by starting the buzzer, and the natural wave length noted. Then the additional inductances La and Lb are added and the corresponding wave lengths are obtained. The coupling between the coils should be kept as loose as possible in order to obtain a more accurate resonance position. Having obtained the two corresponding wave lengths and knowing the values of the two standard inductances La and Lb, we can readily obtain the inductance of the antenna system by substituting the values in the following equation:

$$L_x = \frac{\lambda^2 \, (L_b - L_a)}{(\lambda_b^2 - \lambda_a^2)}$$

Where:

Lx = Inductance of the antenna

λ^2 = Natural wave length of the antenna

L_a = Inductance of one standard

L_b = Inductance of second standard
λ_a = Wave length when coil L_a is in circuit
λ_b = Wave length when coil L_b is in circuit.

The method just outlined for the measurement of the aerial inductance is not very accurate on account of the varying distribution of potential and current along the antenna at the different wave lengths used. It is very difficult to overcome these defects in this kind of work; in fact, it is the most difficult quantity to measure accurately in radio work. The measurement of inductance is very important in all radio work and the novice should not lose sight of its importance.

CHAPTER XV.

Calculation and Measurement of Inductance.

(*Concluded*)

HAVING discussed the methods of both calculating and measuring the inductance of coils, we are now in a position to continue with the design of the most important type of inductance coils used in radio work. We will confine ourselves to the types of coil which are mostly used, namely—loading inductances, loose couplers, variometers and transmitting oscillation transformers.

Before we delve into the actual design of these coils, let us first consider the first fundamental facts necessary for the design. Since the inductance is employed in building up the proper oscillating condition of the circuit and consequently the wave length, we can express this relation by the following formula:

We have first the formula expressing the wave length, *W.L.*, of the open (antenna) oscillatory circuit, thru the primary, L_0, of a loose coupler, loading or tuning coil.

$$W.\,L. = A\sqrt{L \times C}; \qquad (1)$$

Where:—

A = a variable, ranging from 38.15 to 59.6 for short wave lengths.

L = total inductance in centimeters of aerial, including lead-in and loose coupler, tuning coil or loading coil.

C = capacity in micro-farads of aerial, including lead-in.

Those interested in this subject should refer to the excellent article on *"The Design of Large Radio Receiving Transformers,"* by C. S. Ballantine, in the February, 1917, issue of the *Electrical Experimenter,* page 732. The variable factor, 59.6, appearing in the usual wave length formula was there discussed at length, with a graph giving the different values of this function for various wave lengths and aerial inductance to localized inductance ratios.

Considering long wave lengths (10,000 meters and higher) and the design of large loose couplers, we are safe in using the expression:

$$W.L. = 59.6\sqrt{L \times C};$$

Where:—

L = inductance of loose coupler primary and loading coil (if

used); the inductance of the antenna being neglected, owing to its small value compared to the inductance of the loose coupler (or loading coil).

C = capacity of antenna, including lead-in.

For designing short wave apparatus we shall call L_0, the value of the loose coupler (or tuning coil) primary inductance. Then we have:

$$L_0 = \frac{\lambda^2}{3552 \times C} - L; \qquad (2)$$

Where:—

L_0 = inductance of load (loose coupler, tuner, etc.), in centimeters.

λ = maximum wave length to be tuned to.

L = inductance of antenna and lead-in in centimeters.

C = capacity of antenna and lead in in micro-farads. (See tables herewith for these values.)

For long wave apparatus, let L_0 represent the loading coil inductance, plus the inductance of the loose coupler primary (or tuner, if used). Then we have the formula:

$$L_0 = \frac{\lambda^2}{3552 \times C}; \qquad (3)$$

with all values the same as in formula No. 2.

The following tables will be found useful in applying the above equations to the design of loose couplers, etc.

TABLE "A"

Cap. in M.F., Including Lead-in, of 4 Wire Inverted "L" Aerials. Wires Spaced 3 Ft. Apart.

Height	Length of Flat-top in Feet			
in Feet	60	80	100	120
40	.00033	.00042	.00051	.00060
50	.00035	.00043	.00050	.00058
60	.00036	.00044	.00051	.00059
70	.00037	.00045	.00052	.00059
80	.00039	.00046	.00053	.00060
90	.00040	.00048	.00055	.00061
100	.00042	.00049	.00056	.00062

TABLE "B"

Inductance in Cms., Including Lead-in, of 4 Wire Inverted "L" Aerials.

Height in Feet	Length of Flat-top in Feet 60	80	100	120
40	35,000	41,100	47,200	53,310
60	48,800	55,460	62,090	68,700
80	62,400	69,320	76,300	83,300
100	76,260	83,500	90,750	98,020

It is possible to determine approximately the inductance required to produce a desired wave length when the capacity of the total oscillating system is known. When using any of the above formulas, it should be remembered that they include the total value of the unit. Thus, the capacity factor includes the antenna, and condenser capacity, each of which must be determined separately and the capacity of the antenna must be obtained by actual calculation, formula for deriving this quantity having been given on page 732 of the February, 1917, issue of the *Electrical Experimenter*, as well as a table of the capacities of a four wire antenna of different lengths and heights.

The first step in the design of an inductive tuner (having determined the wave length) is the actual size of the instrument, and from this to find the approximate dimensions of the winding tubes to be used. Having these on hand, and knowing the maximum inductance of the primary by equations (2 or 3), we can immediately determine the number of turns that the primary coil will require to obtain the wave length sought, by solving equation (3) of Chapter XIII, for N; in terms of units we obtain the following relation:

$$N = \frac{1}{5d}\sqrt{\frac{L\,(3\,S + d)}{3}} \qquad \textbf{(4)}$$

Where:—

N = total required number of turns.

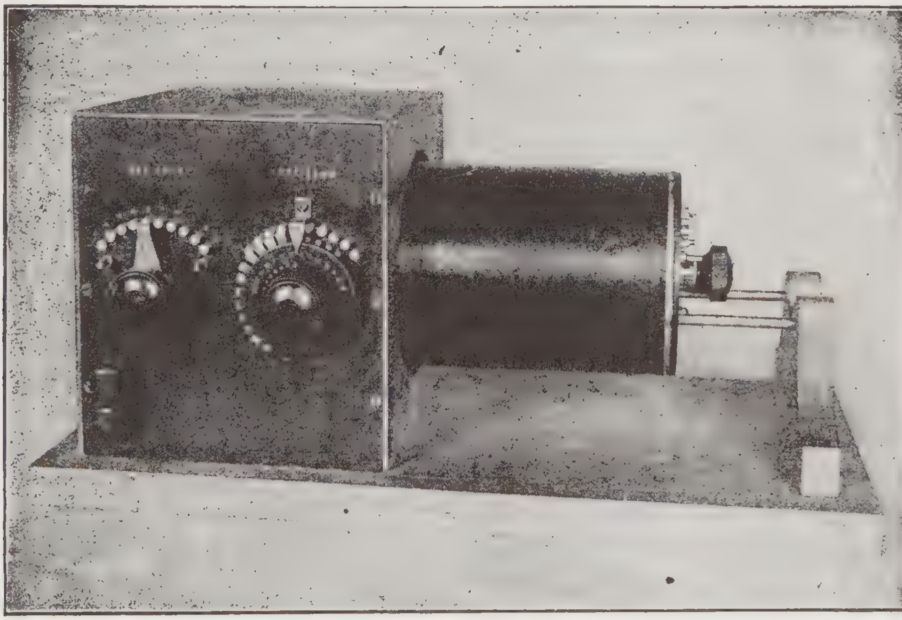
d = diameter of coil in inches.

S = length of coil in inches.

L = inductance required in centimeters.

The inductance of the secondary winding should be such that its wave length should correspond very nearly to the antenna circuit, and that of the primary. If this condition is obtained, then we

have an ideal condition of maximum efficiency and great care must be exercised in bringing about this ideal condition. The value of the secondary inductance must therefore be in the neighborhood of the primary (unless it is to be shunted by a variable capacity), but in practise it is made somewhat larger than that of the primary. It is customary in coupler design to allow one-half inch difference in size of diameters between the primary and secondary tubes and therefore the diameter of the secondary can readily be determined. The number of turns required is deduced from equation (4).



A modern long wave loose coupler, provided with dead-end switches.

The size of wire to be used on the secondary coil is a very important factor in efficient couplers, and the principal factor controlling the diameter of the wire to be used is whether a crystal or Audion detector will be connected in the secondary circuit. Since the latter type is a potential operating device it is essential that the winding should consist of a smaller wire than if the same coil is to be connected to a crystal detector. The reason for this is that the energy received by the secondary winding is so infinitesimally small that any superfluous resistance in the secondary circuit due to small wire

winding destroys the intensity of the rectified current in the telephone receiver; but this condition does not hold true for a potential operating detector where the superfluous resistance is overcome by applying a greater potential in the circuit by the variation of the "B" battery of the Audion circuit. It was found from actual experiment that with an Audion detector, the secondary winding should be made with a gage wire ranging from No. 28 to 32 B&S, while with a crystal detector numbers 24 and 26 were found to give excellent results.

After the primary and secondary coil quantities have been obtained, the specified design is completed and the next step is to consider the general mechanical features of the tuning devices and the manner in which the coils are held in place; the latter will be left to the builder, since each one has his own idea of finishing up an instrument.

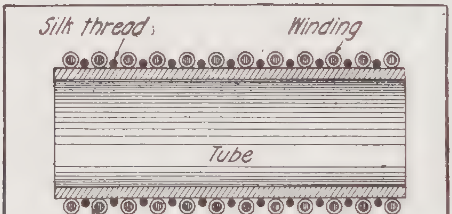


Fig. 1

It is advisable at first in winding the coils, that no shellac or any kind of varnish be applied to the wire to keep it in place, as the capacity dielectric losses between adjacent turns are considerably increased, which naturally decreases the efficiency of the instrument. An ideal method of winding the wire is to cut a very fine thread on the surface of the tube in a lathe, and wind the wire in this thread. If a coil of this kind should be made, hard rubber or Bakelite should be used; the latter is preferable since it does not warp during changes of weather conditions. The method of winding a wire on a threaded tube is also advantageous in reducing the distributed capacity of the winding.

Still another method of winding the wire on a coil upon which a thread can not be machined, is to wind a fine silk thread between adjacent turns. Fig. 1 shows how it is done. This method of winding

has been used considerably in building high grade inductance coils and has proved of sufficient merit to warrant its use with inductive coupler windings.

The question of tap connections and switches is a very important one in designing inductive transformers, and the following points should be kept in mind by the designer: i.e., that all connections from winding leads should be as short as possible; all connections are to be invariably soldered and if possible they should consist of *stranded cable* in order to reduce lead resistance. These terminal leads should be soldered to copper lugs which are connected to the switch point. The latter must be free from any lacquer coating as this increases the high frequency resistance due to a decrease of metal surface. It has been found, however, that if the metal is silver-plated and its surface kept white (not lacquered), that the increase of surface resistance to high frequency currents is negligible. Care should be taken to keep the buttons and switch blade contact as clean as possible, in order to minimize the contact resistance. This also applies to the elimination of the use of lacquer or any other form of polish on switch contact surfaces.

It is advisable in building a coupler to always employ a *dead-end switch* in order to reduce losses due to the distributed capacity inherent in the coil. Both primary and secondary windings should be equipped with one of these switches, and a very excellent and easily constructed type is here illustrated on page 148.

A great deal of inefficiency and loss of energy accrues to the use of wood, hard rubber and fiber for switch panels, as the former usually contains water, acid or other mineral substances, which cause a partially short-circuit on the taps; consequently not permitting the total energy to traverse the winding, which naturally does not permit the total flux induction to take place between the windings.

The fiber and hard rubber panels are not satisfactory for the simple reason that their surface deteriorates in time, and with the latter material, a film of sulfur is formed which collects dust, into which metallic particles lodge. These produce a short-circuit between contacts. Fiber, too, is rather hygroscopic. The best material for the construction of switch panels is Bakelite, which makes an ideal insulator for radio work. It is used on all receiving sets now built by the large commercial radio companies.

For the benefit of those who desire to build an excellent 4,000 meter loose coupler, a complete working drawing of one is given here.

There is still another type of inductance coil which has recently proven very satisfactory for tuning long waves, and this is the *multilayer coil.* During the last few years considerable criticism was made regarding the use of these coils, due to the untoward dis-

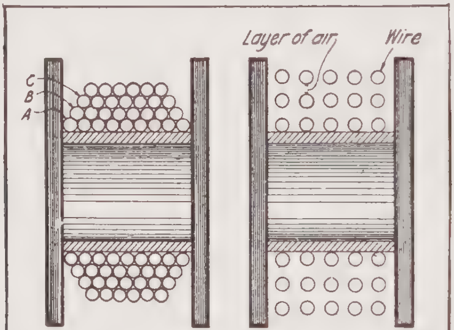


Fig 2 Fig 3

tributed capacity effect produced by adjacent layers. However, these criticisms lost themselves among certain radio engineers who have been working on this problem and notably the Telefunken experts, who have evolved the so-called *staggered winding* multilayer coils, which consists of tapering layers of wire on top of each other in the manner shown in Fig. 2. The first layer A was wound in the usual way; the second layer B was started from the center of the first two turns as shown; the third between the first two of the second layer and so on until the last winding which consisted of a single turn.

Great precaution must be exercised in making the turn for the approaching next layer. This is done by making a sharp bend in the wire. This type of coil has been used with success for a number of years by the Telefunken concern, and they are still being used. They are excellent for building inductances for long wave lengths in a small space.

Something new in multilayer inductances is shown in Figs. 3 and 4. This design is due to Prof. J. H. Morecroft of Columbia University, who has done considerable research work in radio.

It was pointed out in an article on "Distributed Capacity and

Its Effect" in the May, 1917, issue of the *Electrical Experimenter*, that on the long single-layer coil the distributed capacity increased with an increase of coil length, and that the potential effect is greatest at the end of the coil. It naturally follows that with extremely long coils the voltage is extremely high at their ends, as compared with any of the apparatus used in the tuning circuit. It has usually been considered that multilayer coils had considerably greater distributed capacity than those of the single layer type, due to the proximity of the layers making up the coil, but it has recently been found that by properly constructing such coils, the inherent capacity is minimized. This fact was proved by constructing two multilayer coils where the layers of each winding were separated by a layer of air as indicated in Fig. 3. One of these coils has twenty layers, the other ten layers, yet the distributed capacity was found to be very low, or of the order of 25 centimeters and an inductance value of about 70 milli-henries.

The winding is made over a cagelike insulating reel, by eight wood pins passed thru two end pieces. After one layer is wound a strip of cardboard is placed across the winding right over each wooden peg. The next layer is then wound on and the cardboard

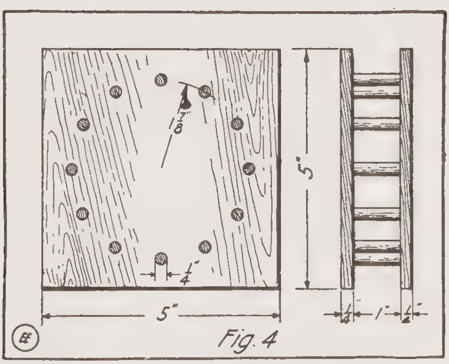
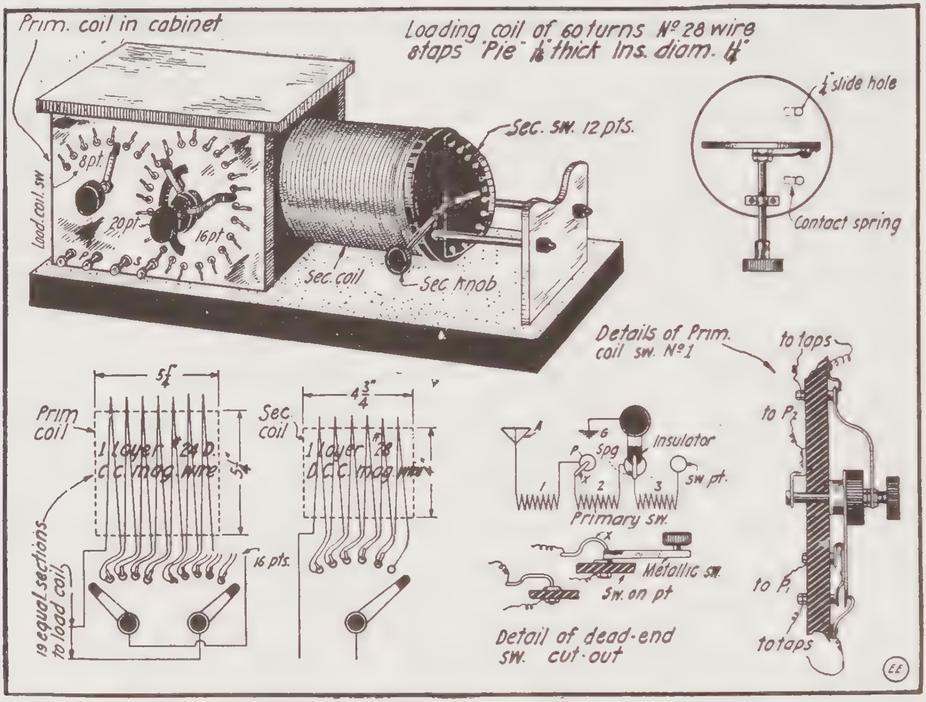


Fig. 4

strips give an air space between the two layers. Each successive layer is wound in a similar manner, giving an air space between layers.

The inductance of multilayer coils of the Morecroft type is obtained from equation No. 10, Chapter XIII. The notation of symbols is the same. The cross-sectional diagram, Fig. 2, there given shows a multilayer coil without an air space between layers, but the relation

of the units holds true for the air spaced coils, since the dimension of the air space must be considered in the actual calculation.



Details of efficient, medium wave length, loose coupler for radio reception.

In determining the capacity of multilayer coils the following equation has been found quite accurate:

$$C = \frac{a}{420}\left[\frac{b\,e}{c\,x} + 0.8\right] \qquad (5)$$

Where:—

C = capacity in milli-microfarads.

a = means radius of coil (inches).

b = axial length of coil (inches).

e = 2.718.

c = winding depth of coil (inches).

x = insulation thickness between layers in mils.

The first part of the equation represents the capacity due to the dielectric flux between layers, and this varies with the different parts of the coil as the variation of voltage is different at the various lengths of the winding. It also takes care of the dielectric losses due to the wire, and for air, which is used in the Morecroft coils, it is unity. Various other losses are encountered in these types of coil such as eddy current, hysteresis and skin effect.

The general construction and dimensions of the Morecroft multi-layer coil is shown in Fig. 4. The ends are made from well-seasoned wood and the ¼″ dowel pegs are glued into the holes made in the side pieces as indicated. The winding consists of ten layers of No. 30 silk covered wire. Each layer consists of 75 turns.

The great advantages of these coils are that long wave lengths can be tuned with a small size coil, and the capacity effect of the operator's body upon the coils is minimized, which eliminates the dëtuning effect on the oscillating Audion circuit when the operator stands near his apparatus. This effect is very noticeable when the long inductance coils are employed.

APPENDIX

TABLES

AND

FORMULAE

TABLE OF DIMENSIONS OF SPARK COILS.

Suitable for Use in Wireless Telegraphy. These Coils Give a Very Heavy Fat Spark.

Length of Spark	⅛″	¼″	⅜″	½″	¾″	1″	2″	3″	6″	12″
Length of Core........	3″	3¾″	4¾″	6″	7″	8½″	11″	12½″	16″	21″
Diameter Core	¼″	⅜″	½″	½″	¾″	1″	1⅛″	1⅜″	1⅝″	1⅞″
No. Prim. Wire........	23	23	22	19	16	16	14	14	12	10
Layers Prim.	2	2	2	2	2	2	2	2	2	3
No. Sec. Wire.........	34	34	34	34	34	34	33	32	32	30
Wgt. Sec. Wire.........	¼ Lb.	½ Lb.	¾ Lb.	1 Lb.	1½ Lbs.	2 Lbs.	4 Lbs.	8 Lbs.	16 Lbs.	30 Lbs.
No. Sec. Pies..........	1	1	2	2	4	4	8	16	32	80
No. Tinfoil Sheets.....	30	45	55	65	80	120	120	180	220	300
Size of Sheet..........	2″ x 1″	2″ x 1½″	4″ x 2″	4″ x 2″	4″ x 4″	7″ x 5″	9″ x 7″	9″ x 7″	9″ x 9″	12″ x 8″
Wall of Insul. Tube....	1/32″	3/64″	1/16″	1/16″	⅛″	⅛″	3/16″	¼″	5/16″	⅜″
Prim. Volts	2	2	4	4	6	12	12	12	16	20

CLOSED CORE TRANSFORMER DATA.

For Use on 110 Volts, A. C. 60 Cycles.

Capacity in Kilowatts	Length Iron in Inches	Width of Iron in Inches	Thickness and Width Core	No. Primary Wire D.C.C.	Weight Primary Wire in Lbs.	Layers in Primary	Primary Current in Amperes at Full Load	Weight of Iron in Lbs.	Length Primary Coil in Inches	Weight of Sec. Wire, Lbs.	No. Pies ¼" Thick	Turns Per Pie	Size of Square Opening in Pie	Length of Secondary Winding	Amperes in Sec. Lowest Voltage	Sec. Voltage on 4 Layers of Primary	Sec. Voltage on 3 Layers of Primary	Sec. Voltage on 2 Layers of Primary	Per Cent of Efficiency	No. Secondary Wire D.C.C.	Average Sending Range in Miles in Daylight Over Land
½	14	7	1.4	13	6	4	5	20	10.2	8	25	2092	1.9"	9.2"	.046	11908	17460	23012	94	34	75*
1	15	8¼	2	10	11.3	4	9.6	41	10	11	24	1611	2.5"	9"	.086	12363	18261	24880	94	32	150*
2	17½	8¾	2¼	8	13.5	3	18.2	56	12	21	30	920	2.75"	11"	.153		12440	16580	95.7	28	300*
3	18	9½	2½	6	19	3	27.3	75	12	27	30	708	3"	11"	.252		11920	15893	96.5	26	450*

OPEN CORE TRANSFORMERS.

For Use on 110 Volts, A. C. 60 Cycles.

Capacity in Kilowatts	Length of Core in Inches	Diameter of Core in Inches	No. B. & S. D.C.C. Primary Wire	Layers in Primary	No. B. & S. S.S.C. Secondary Wire	No. of Pies ¼" Thick†	Weight of Secondary Wire	Thickness Wall of Hard Rubber Tube Over Primary and Same Length	Average Sending Distance in Miles in Daylight Over Land
½	11	1¼	14	2	34	26	8	¼"	75
1	14	1½	12	2	32	30	12	⅜"	150
1½	16	2	12	2	30	52	18	½"	250
2	18	2½	10	2	28	60	22	⅝"	300
3	24	3	8	3	26	70	30	¾"	450

* Sending distance over water or at night is twice this value.
† Pies to be insulated from one another by two discs of empire cloth.

APPENDIX.

HIGH POTENTIAL GLASS PLATE CONDENSERS FOR WIRELESS TRANSFORMERS.

Kilowatts Capacity	Total No. Glass Plates for Series Parallel Condenser of 2 Units	Size of Glass Plates — Thickness .05 Inches	Size of Metal Foil Leaves	Microfarads* Capacity at 60 Cycles
¼	18	12″ x 14″	8″ x 10″	.0048
½	34	12″ x 14″	8″ x 10″	.0095
1	40	16″ x 19″	10″ x 13″	.019
2	80	16″ x 19″	10″ x 13″	.037
3	120	16″ x 19″	10″ x 13″	.056
4	160	16″ x 19″	10″ x 13″	.074
5	200	16″ x 19″	10″ x 13″	.093

Note: *Microfarads capacity required at 120 cycles will be one-half this value.

HIGH POTENTIAL GLASS PLATE CONDENSERS FOR INDUCTION COILS.

Length of Spark in Inches	Total No. Glass Plates for Multiple Condenser of 1 Unit	Size of Glass Plates — Thickness .05 Inches	Size of Metal Foil Leaves	Microfarads Capacity
½	3	8″ x 10″	6″ x 8″	.0024
1	6	8″ x 10″	6″ x 8″	.004
2	12	8″ x 10″	6″ x 8″	.008
3	18	8″ x 10″	6″ x 8″	.012
6	14	16″ x 19″	10″ x 13″	.024
8	18	16″ x 19″	10″ x 13″	.032
10	22	16″ x 19″	10″ x 13″	.040
12	28	16″ x 19″	10″ x 13″	.048

APPENDIX.

TABLE OF INSULATED MAGNET WIRE.

Size B. & S. Gauge	Turns Per Linear Inch				
	Enameled	Single Cotton	Double Cotton	Single Silk	Double Silk
20	29	25	23	27	26
21	32	28	26	31	29
22	36	31	28	34	32
23	41	34	31	38	36
24	45	37	33	42	39
25	51	41	36	47	43
26	56	45	39	52	46
27	64	49	42	57	52
28	71	54	45	63	56
29	79	58	48	70	62
30	88	64	57	77	67
31	100	69	58	85	72
32	112	75	60	93	78
33	134	81	64	102	84
34	140	87	68	112	91
35	156	94	73	120	97
36	173	101	78	130	104
37	201	108	84	141	110
38	225	115	89	151	117
39	256	122	95	163	123
40	288	130	102	178	129

DOUBLE COTTON-COVERED MAGNET WIRE.

Size B. & S. Gauge	No. Turns per Linear Inch	Size B. & S. Gauge	No. Turns per Linear Inch
4-0	1.70	7	6.08
3-0	2.00	8	6.80
2-0	2.32	9	7.64
1-0	2.65	10	8.51
1	2.99	11	9.56
2	3.36	12	10.60
3	3.80	13	11.88
4	4.28	14	13.10
5	4.83	15	14.68
6	5.44	16	16.35

APPENDIX.

FEET PER POUND OF INSULATED MAGNET WIRE.

No. of B. & S. Gauge	Single Cotton 4-Mils	Double Cotton 8-Mils	Single Silk 1¾-Mils	Double Silk 4-Mils	Enamel
20	311	298	319	312	320
21	389	370	403	389	404
22	488	461	503	493	509
23	612	584	636	631	642
24	762	745	800	779	810
25	957	903	1005	966	1019
26	1192	1118	1265	1202	1286
27	1488	1422	1590	1543	1620
28	1852	1759	1972	1917	2042
29	2375	2207	2570	2485	2570
30	2860	2534	3145	2909	3240
31	3800	2768	3943	3683	4082
32	4375	3737	4950	4654	5132
33	5390	4697	6180	5689	6445
34	6500	6168	7740	7111	8093
35	8050	6737	9600	8534	10197
36	9820	7877	12000	10039	12813
37	11860	9309	15000	10666	16110
38	14300	10636	18660	14222	20274
39	17130	11907	23150	16516	25519
40	21590	14222	28700	21333	32107

APPENDIX.

TABLE OF SPARKING DISTANCES.

In Air, for Various R. M. S. Voltages Between Needle Points.

Volts	Distance Inches	Centimeters	Volts	Distance Inches	Centimeters
5,000	.225	.57	60,000	4.65	11.8
10,000	.470	1.19	70,000	5.85	14.9
15,000	.725	1.84	80,000	7.10	18.0
20,000	1.000	2.54	90,000	8.35	21.2
25,000	1.300	3.30	100,000	9.60	24.4
30,000	1.625	4.10	110,000	10.75	27.3
35,000	2.000	5.10	120,000	11.85	30.1
40,000	2.450	6.20	130,000	12.95	32.9
45,000	2.95	7.50	140,000	13.95	35.4
50,000	3.55	9.00	150,000	15.00	38.1

TABLE OF UPPER HARMONICS.

The component sine curves making up resultant alternating or wireless waves are commonly alluded to as *harmonics*. The following table shows at a glance the frequencies and the wave lengths of the (upper) odd and even harmonics, from 1 to 15 inclusive. The lower harmonics are the reciprocal of these values.

Odd Harmonics	Even Harmonics	Frequency of Harmonic	Wave Length of Harmonic
1		$f_h = 1f$	$\lambda_h = 1\lambda$
	2	$= 2f$	$= 1/2\lambda$
3		$= 3f$	$= 1/3\lambda$
	4	$= 4f$	$= 1/4\lambda$
5		$= 5f$	$= 1/5\lambda$
	6	$= 6f$	$= 1/6\lambda$
7		$= 7f$	$= 1/7\lambda$
	8	$= 8f$	$= 1/8\lambda$
9		$= 9f$	$= 1/9\lambda$
	10	$= 10f$	$= 1/10\lambda$
11		$= 11f$	$= 1/11\lambda$
	12	$= 12f$	$= 1/12\lambda$
13		$= 13f$	$= 1/13\lambda$
	14	$= 14f$	$= 1/14\lambda$
15		$= 15f$	$= 1/15\lambda$

f denotes the frequency of the resultant curve, in cycles per second.
λ denotes the wave length of the resultant curve.

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